

Michael Durstewitz
Bernhard Lange *Eds.*

Sea – Wind – Power

Research at the first German
offshore wind farm Alpha Ventus



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Editors

Michael Durstewitz
Fraunhofer-Institut für Windenergie
und Energiesystemtechnik IWES
Kassel, Germany

Bernhard Lange
Fraunhofer-Institut für Windenergie
und Energiesystemtechnik IWES
Bremerhaven, Germany

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Foreword by the German Federal Minister for Economic Affairs and Energy



The use of both onshore and offshore wind energy is a key element in Germany's energy transition. Today, onshore wind energy is already the primary source of renewable energy in electricity generation in Germany. The increased expansion of offshore wind turbines still offers a great deal of potential. However, it also requires a lot of innovative solutions to be developed in the areas of construction and operation.

The research undertaken at the first German offshore wind farm Alpha Ventus has played a crucial part in helping to build up knowledge and expertise in what is still a very young sector in energy generation in Germany. It is particularly pleasing that the various research projects could be coordinated with one another so well, and that it has been possible to combine the different interests of researchers, facility operators, and plant manufacturers, whilst also ensuring that expansion work is environmentally sound. The Alpha Ventus wind farm is a pioneering venture which – together with the research initiative 'Research at Alpha Ventus – RAVE' – has laid the foundations for German projects in the area of offshore wind energy. The results of the research are outstanding – something which is also reflected in the level of international interest that has been attracted.

There is, of course, still a great deal of research yet to be carried out on developing the use of wind energy in Germany. We will only be able to use the potential that exists in this field if we continue to reduce the costs of electricity from wind energy and continue to raise grid security. Doing so will enable Germany's wind sector to stay competitive in the long term.

Given this background, the primary aim of the research funding provided by the Federal Ministry for Economic Affairs and Energy is to reduce both the investment and the operating costs for wind-powered installations. The state-of-the-art in German wind-power technology is impressive – with German industry setting international standards based on high-capability wind-powered installations 'Made in Germany'.

When it comes to the expansion of wind power into the future, it will be crucial to ensure that the electricity generated by wind turbines can be reliably integrated into the public grids. Indeed this is one of the priorities that the Federal Ministry for Economic Affairs and Energy has set in the area of energy research. Further research is needed in areas such as optimising

the grid connection of offshore wind farms, load and generation management, wind-energy-specific aspects of storage, and improvements in wind forecasts.

German companies, universities, and research establishments are among world leaders in wind energy thanks to the innovations that are being generated in this field. Research activities are being supported by German manufacturers and service providers, who are developing solutions designed to meet the specific requirements of foreign markets. The Federal Ministry for Economic Affairs and Energy is providing funding for these activities with the aim of ensuring the highest possible value generation in wind energy in Germany and, through this, of making the German wind industry internationally competitive.

I am delighted that an essential overview of the many different research projects being funded by the Federal Government as part of the Energy Research Programme now appears in book form. I wish you interesting reading and hope that this publication will serve as a source of inspiration to you.

Sincerely yours,

Sigmar Gabriel

Federal Minister for Economic Affairs and Energy

Foreword by the Chair of the Offshore Wind Energy Foundation



The construction of the Alpha Ventus test field played a significant role in the development of offshore wind energy in Germany. Within five years of it being commissioned in April 2010 there were wind farms in the German North and Baltic Seas with an output of 3,294 megawatts connected to the grid. And based on the investment decisions and business planning already made, the output will have more than doubled by 2020 – while optimistic predictions reckon that the government-set upper limit of 7.7 gigawatts will be fully utilised. This breakthrough of this new technology, which had no easy task in overcoming many teething troubles, would not have been possible without the extensive research projects and their findings that were part of the RAVE research initiative.

Over 50 universities, research institutions and businesses have been involved in numerous individual projects dealing with the solution of problems that would improve offshore wind turbine technology, making it safer and more profitable while also optimising its compatibility with the marine environment. The entire German offshore wind industry has profited from this.

The foundation would therefore like to thank all the scientists who have been involved in this national offshore wind research project and who have thus helped a new technology to make its breakthrough.

On behalf of this research community the foundation would especially like to thank Project Management Jülich (PtJ) and the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), who supported and coordinated the individual scientific works, and aggregated all the results.

The RAVE research network has made a great contribution to the development of offshore wind energy in Germany.

Jörg Kuhbier

Chairman, Offshore Wind Energy Foundation

CSI Test Field, CSI Offshore

Publisher's Foreword

RAVE: 1) a frolicking crowd, a dancing mass of people, a swarm 2) abbreviation of Research at Alpha Ventus. So ambiguous and yet so applicable, because the installation and investigation of Germany's first offshore wind farm, Alpha Ventus, also proved to be a ride over the North Sea, for everyone involved.

The start signal for RAVE was given just eight years ago and it is already hard to visualise what it was like back then. Nobody had ever had any experience of erecting wind turbines so far out at sea, over 40 kilometres from the nearest piece of dry land. Nor did anyone have any experience of building wind turbine foundations in water 30 metres deep. The foreseen five-megawatt wind turbine generation was also new and had never been tested out at sea. But we are in a very different position today; nobody asks the question "Is that at all possible?" any more. Five-megawatt turbines are now old hat. Today around 800 offshore wind turbines are operating in German waters, and over 3,200 in Europe. That is also thanks to Alpha Ventus and RAVE.

Both of them are success stories. With around 4,500 full load hours of wind power a year, Alpha Ventus is very impressive. This is especially so compared with other European offshore wind farms – even though Alpha Ventus is a test field. The experiences made and the operating results of Alpha Ventus have significantly contributed to building trust in the technology, which is a prerequisite for further expansion. And this indeed came to pass; in 2015 there was a record 2,282 megawatts of new offshore installations in Germany. There are now offshore wind farms with a total of around 3,300 megawatts on grid. The government goal of achieving its short-range target of 6,500 megawatts of offshore wind power by 2020 appears feasible. Based on current information, around 80 % of the projects planned to date have the financing in place.

RAVE is also a success story. Never in the history of wind power has there been such a large coordinated research initiative, in which the industry and research institutions have acted so in concert. And with success, because within just a few years not only have the manufacturers involved been able to develop their wind turbines further, but based on the research findings they have also been able to develop new guidelines that are now applied across the entire industry. Last but not least, the project has also provided new fundamental knowledge, ranging from the behaviour of porpoises to loads caused by breaking waves. Within just a few years, German offshore wind energy research has made it to the top of the international league – as proven by the many publications and conference contributions.

RAVE has been a joint effort. Despite, or perhaps because of, all the obstacles that had to be overcome. "We were all bitten by the offshore bug." Us, all the researchers involved in Alpha Ventus, Germany's first North Sea wind farm. We are proud that this test field came to fruition – and that we scientists were able to research in the field. Also very important was the financial support that first enabled this research work, for which we must thank the Project Management Jülich PtJ and the Federal Ministry of Economics and Energy. Over 50 universities, research institutes and businesses have been involved in the RAVE research. Their results help to further develop offshore wind energy use.

An incredible amount has been achieved in the past ten years. Our knowledge has increased enormously. But as we all know, miracles take a bit longer, and that is something we should bear in mind when all that is discussed nowadays is how quickly we can expand offshore wind power and how quickly the costs can be reduced. Despite the massive advances made, the offshore wind industry is still a very young industry, which still needs a long time – which it must also be allowed – in order to complete its knowledge, optimise its technology and gather operational experience. Offshore wind farms are built for an operational life of at least 20 years and even the first German offshore wind farm, Alpha Ventus, is not even half way there yet.

Research can make a contribution, and wants to. The long-term behaviour of materials and components in the harsh offshore conditions has to be investigated and understood. Deeper knowledge enables innovations that can reduce the cost of power generated offshore. New approaches in planning, production, construction and operation of offshore wind farms have to be conceived, developed and tested. In ten years' time wind farms will look very different, and also cost less than today.

One last question remains to be asked. Who is this book really aimed at? Everyone interested in offshore wind power, and everyone who wants to understand what research issues had and have to be solved if they are to become reality. In other words, it is for everyone who wants to know more about the work and (interim) results from Germany's first offshore test field. And it is for those who do not want to first study engineering or physics if they are to understand it. This book is an attempt to express the scientific findings of RAVE in a way that is generally understandable. If anyone wishes to have more detailed information we recommend that they read the final reports of the respective research projects, look at the Internet presentations or speak to those involved in the projects.

Offshore wind power in Germany is only just getting started. Research into it continues, and hopefully the success story will also. We researchers want to make our contribution and look forward to doing so.

Foreword to the English edition

After more than half a decade of research involving over 50 universities, research institutes and businesses, Alpha Ventus is the world's most thoroughly investigated offshore wind farm. This translation of the German book "Meer – Wind – Strom" will also give a wider international readership the opportunity to share in the results of the RAVE research project.

Michael Durstewitz



Dr. Bernhard Lange



Credits

We would like to thank

- All the authors for their effort and involvement, for their patience in explaining everything, their work in correcting, for their courage and willingness to tread new paths with this book.
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- The Federal Ministry for Economic Affairs and Energy and Project Management Jülich, who made the realisation of this work possible.
- And the many other helpers who supported us during the production and who contributed to the publication of “Sea – Wind – Power”.

Michael Durstewitz, Bernhard Lange, Björn Johnsen

Kassel, Bremerhaven, Hannover in February 2016

Contents

List of Authors	xxii
-----------------------	------

I Construction, Operation, Measurement, Coordination

1	Metamorphoses of an Offshore Wind Farm.....	3
	<i>Björn Johnsen</i>	
1.1	In the Beginning Was the Sea.....	4
1.2	Prerequisites and Previous Experience	5
1.3	Foundation Concepts: Something New on the Sea Bed	5
1.4	Delayed Completion	6
1.5	Installation, Logistics and Cabling.....	7
1.6	Operation, Maintenance and Farm Control System	7
1.7	Money and Its Usages	8
1.8	Sources	9
2	Who, What, When, Why and Above All – Where to?.....	11
	<i>Björn Johnsen</i>	
2.1	Sources	13
3	A Thousand Sensors, from the Blade Tip to the Bottom of the Sea.....	17
	<i>Kai Herklotz, Thomas Neumann, Wilhelm Heckmann, Hans-Peter Link, Copy edited by Björn Johnson</i>	
3.1	Measurement Service: One for All	18
3.2	Coordination, Organisation, Exploitation.....	18
3.3	Tripod Is Also Hard to Access on Land	19
3.4	An Obstacle Course Before and out at Sea	20
3.5	The Tides and Maltreated Measuring Buoys	22
3.6	Only 30 % Accessible by Ship in Winter	23
3.7	Firmly Entrenched in the Ground, even with Scour Holes	24
3.8	Logistics: (No) Ship will Come	26
3.9	Just Keep on Going.....	27
3.10	Sources	27

II Foundation and Support Structures

4	A Firm Hold in Rough Seas.....	31
	<i>Raimund Rolfes, Moritz Häckell, Tanja Griefmann, Text written by Björn Johnson</i>	
4.1	Introduction	32
4.2	The Tripod as Wave Breaker	32
4.3	Steel Structure with an Ideal Figure	33

4.4	Cavity and Grout	33
4.5	Rust on the Tube	34
4.6	Immersion Bath for the “Problem” Plates	35
4.7	Monitoring Is Everything	35
4.8	Scouring, the (Un)Known Entity	38
4.9	Scour Protection Using Concrete Chains	39
4.10	How Much Can a Pile Bear?	39
4.11	Close to Reality	40
4.12	A Software Puzzle Gets Put Together	41
4.13	Sources	43
5	Life Goes on	45
	<i>Raimund Rolfes, Tanja Griesßmann, Text written by Björn Johnson</i>	
5.1	The Journey Is the Reward	46
5.2	Efficient Data Management	46
5.3	Research Put into Practice	47
5.4	Despite Rust and All that: Is There Anything After the End of Service Life?	47
5.5	Model Tests Are Good, but Are Calculation Models Better?	48
5.6	The Gordian Tube Knot	50
5.7	Where Will It All End – Automatic Service Life Calculation	51
5.8	Sources	51
6	Please Avoid Tilting	53
	<i>Werner Rücker, Pablo Cuéllar, Steven Georgi, Krassimire Karabeliov, Matthias Baeßler, Copy edited by Björn Johnsen</i>	
6.1	Everything Rests on the Pile	54
6.2	Pore Water Pressure: Even a Drop Weighs Heavy	54
6.3	Measuring and Expanding	55
6.4	Between Ground Subsidence and Pore Water Pressure	57
6.5	Extreme Storms Loosen Things up	57
6.6	The Burden with the Load Thereafter	58
6.7	Sources	58
7	Uncharted Territory on the Seabed	61
	<i>Matthias Baeßler, Pablo Cuéllar, Steven Georgi, Krassimire Karabeliov, Werner Rücker, Copy edited by Björn Johnsen</i>	
7.1	Getting the Balance Right	62
7.2	Observing and Monitoring	62
7.3	All Beginnings: The PC and a System Identification Procedure	63
7.4	Field Trials at the Bottom of the Berlin Glacial Valley	64
7.5	The Early Piles: Still Not Very Resilient	64
7.6	No Signal in Normal Operation	65
7.7	Testing out at Sea Still Not Completed	66
7.8	Outlook: Please Continue to Develop Countermeasures	67
7.9	Sources	67

III Turbine Technology and Monitoring

8	Long-Lived Despite Harsh Winds	71
	<i>Jan Kruse, Copy edited by Björn Johnsen</i>	
8.1	The Gearbox – Highly Stressed	72
8.1.1	A Small Crane on Board Instead of a Big Jack-up Rig out at Sea	72
8.1.2	Sufficient Capacity for a Long Service Life	73
8.1.3	Online Oil Tests to Combat Salt in the Gears	74
8.2	SCADA, Interfaces and the Like	75
8.2.1	Standard Communication Interface	75
8.2.2	Closely Linked: Data Flow and Communication Technology	75
8.3	Grid Integration of the 5M	76
8.3.1	Power Plant Characteristics	76
8.3.2	System Services – the Wind Turbine on Grid	76
8.3.3	Successful Simulation: The Grid Simulator	76
8.4	Intelligent Control	77
8.4.1	Recently in the Tower: No Wobble	77
8.4.2	The End of “Manual Control”	78
8.5	Sources	78
9	Wind in the Blades	79
	<i>Jan Kruse, Copy edited by Björn Johnson</i>	
9.1	What Is Required of Rotor Blades	80
9.2	The Work Packages for the New Blade	80
9.2.1	In Abundance	80
9.2.2	Process Development and Mould-Making	81
9.2.3	Stackable Transport Racks and a Set of Prototype Blades	82
9.2.4	Blade Test and Measurement “in the Field”	82
9.3	Advances Made by the Others	83
9.4	Outlook: What Have We Got from It, and What Can We Still Get from It?	83
9.5	Sources	83
10	The Wiser Blade Knows When to Yield	85
	<i>Björn Johnsen</i>	
10.1	Withstanding – and Exploiting – 100 Million Gusts of Wind	86
10.2	Turbulences from the Front	86
10.3	Act Early rather than too Late	87
10.4	Twisting Instead of Pitching?	87
10.5	By Bend or by Twist	88
10.6	The Bigger the Flap, the Easier the Influence	88
10.7	Don’t Just Work Backwards, Also Work Forwards for a Change	90
10.8	Sources	90
11	The “Exclusively Offshore” Wind Turbine	91
	<i>Gerrit Haake, Annette Hofmann, Copy edited by Björn Johnsen</i>	
11.1	Objectives	92
11.2	Forward Sweep Instead of Bending Moments	92

11.3	Learning Objective: Ruggedness	93
11.4	Before We Take to the High Seas: Testing	95
11.5	Not Quite Like Your Living Room Yet: Climate Control in the Inner Tower	95
11.6	Maintaining Maintenance	97
11.7	Keeping in Touch	97
11.8	Keep Turning in High Wind	98
11.9	Helicopter Air-Drop Platform: Abseil!	98
11.10	Drivetrain in Long-Term Test	98
11.11	Sources	100
12	Shooting into the Wind with Laser Beams	101
	<i>Björn Johnsen</i>	
12.1	How It Works	102
12.2	Not Just Research for Research's Sake	102
12.3	Lidar Technology	103
12.3.1	Snowfall Test in Swabia	103
12.3.2	Scanner System and Specification Offshore	104
12.3.3	Wind Measurement Buoy on the Crest of a Wave?	104
12.4	The Burden of the Power Curve	105
12.4.1	From Wmo to Demo	105
12.4.2	Lidar on the Nacelle	106
12.5	Turbulent Wind Fields in Front and Behind	107
12.5.1	Inflow from the Front, Initial Investigations into System Control	107
12.5.2	Simulation Is Part of Testing	107
12.5.3	Like a Smoke Trail – the Wind Loads Behind the Turbine	108
12.6	Quo Vadis? New Offshore Measuring Method and FGW Guidelines	109
12.7	When the Nacelles Have Lidar	109
12.7.1	Modern Control Systems First React upon Wind Impact	109
12.7.2	Robust and Suitable for Industrial Use	110
12.7.3	Collective “Blade Feed Forward Control” Before the Wind Hits?	110
12.8	Sources	111
13	“Get Out of My Wind”	113
	<i>Björn Johnsen</i>	
13.1	Measure More with Multi-Lidar	114
13.2	A Deficit Is Obvious – Where the Wind Is Concerned	115
13.3	Satellites, Lidars and a Source Code	115
13.4	More Accuracy Without a Mainframe Computer	117
13.5	Sources	117
14	The First Test for Offshore Turbines	119
	<i>Björn Johnsen</i>	
14.1	Wish, Will and Achievement	120
14.2	Air and Power Curve: the Greatest Deviations by Stable Atmospheric Conditions	120
14.3	Measuring at Hub Height: The Standard Is Not Enough	120
14.4	What Is Really Going on Behind the Turbine?	121
14.5	Not Enough Chaos in the Simulation Model	123

14.6	When Super Computers Begin to Fume – Part I: In the Turbine and Around the Turbines	123
14.7	When Super Computers Begin to Fume – Part II: From Inflow to Distant Wake and to the Wake of the Whole Wind Farm	124
14.8	Verification of the Turbine Dynamics: First Steps	126
14.9	Integration and Identification	126
14.10	Despite All the Effort: Still Only Little “Strain Wear”	128
14.11	Load Monitoring from Only Standard Data?	129
14.12	Sources	130
15	Load, Load Monitoring, and Load Reduction	131
	<i>Björn Johnsen</i>	
15.1	Corrections Welcome	132
15.2	Interaction in a Different Way – the Tower Vibrates as well	133
15.3	Load-Reducing Regulation and Load Monitoring	134
15.4	Loads Along the Rotor Blades	134
15.5	Always Further, Always Higher?	134
15.6	Small Unmanned Aircraft: To New Heights Without Daedalus	134
15.7	... And with Ice on the Blade Tips	135
15.8	Did the Storm Contravene the Rule Book?	135
15.9	Sources	135
16	Different than Previously Assumed	137
	<i>Stefan Emeis, Copy edited by Björn Johnsen</i>	
16.1	Nobody Is Perfect – Not Even Fino	138
16.2	Not “Just Air”: Boundary Layers in the Atmosphere	138
16.3	Of Young and Old Waves	139
16.4	Describing the Sea Without Wave Data	141
16.5	Outlook	142
16.6	Sources	143
17	Sometimes It Almost Bubbles Like a Witches’ Cauldron	145
	<i>Stefan Emeis, Thomas Neumann, Richard Foreman, Beatriz Cañadillas, Copy edited by Björn Johnsen</i>	
17.1	Installation Takes Precedence over Studying	146
17.2	Over the Sea It’s Always on the Up and Up	147
17.3	Like in the Classroom: It Gets More Turbulent Behind the First Row	147
17.4	Outlook: Keep on Writing!	151
17.5	Sources	151
18	Artificial Intelligence and Automatic Self-Organisation	153
	<i>Stephan Oelker, Marco Lewandowski, Klaus-Dieter Thoben, Dirk Reinhold, Ingo Schlalos, Copy edited by Björn Johnsen</i>	
18.1	Wind Farms Inaccessible for Six Months?	154
18.2	Inspired by the Good Old Used Car	154
18.3	It Takes a Breakdown to Trigger the Maintenance Process	154
18.4	About the Peaceful Coexistence of Systems	155

18.5 **Gathering Data: From Gear Oil to “Concert Pitch” of the Blade Rotation** 155

18.6 **The Process Machine Is Running**..... 156

18.7 **A Different Selection for Once: Please Present a Wide Range of Faults** 157

18.8 **When the Offshore Machines Negotiate About Maintenance with One Another** 158

18.9 **Sources** 158

19 Well, How are They Running? 159

Berthold Hahn, Stefan Faulstich, Volker Berkhout, Copy edited by Björn Johnsen

19.1 **Going from Land out to Sea** 160

19.2 **More Than Just Counting Kilowatt Hours** 160

19.3 **A Word in Your Ear: Confidentiality and Individual Evaluations** 160

19.4 **Involving the Actors: Persuasive Efforts** 161

19.5 **Events, Results – and a Library!** 163

19.6 **Zeus Makes It Possible** 164

19.7 **“IEA Wind Task” – More than Just a Talk Show** 165

19.8 **Over 200 Offshore Turbines Are Involved** 165

19.9 **Sources** 167

IV Grid Integration

20 Wind, the Wild Boy in the Power Plant Family 171

Arne Wessel, Sebastian Stock, Lüder von Bremen, Copy edited by Björn Johnsen

20.1 **The Grid and Nothingness** 172

20.2 **Maintaining Voltage and Frequency** 172

20.3 **Together We Are Strong – Let’s “Cluster”!** 173

20.4 **The Main Thing Is What Comes out at the Other End** 173

20.5 **Most Frequently at Rated Output: Energy Yields and Power Fluctuation in Alpha Ventus** 173

20.5.1 **Fluctuations: The Wind Farm Compensates for Individual Turbines** 175

20.5.2 **It Gets Shady Starting with the Second Row** 175

20.5.3 **Never Quiet on the Western Front** 175

20.5.4 **Calm Is when It Still Blows: 16 Hours Bad, 20 Sad** 177

20.6 **Everything Flowing? From the Beginning of all Wind Power Forecasts to “Total Fluc”** .. 178

20.6.1 **More Accurate by the Dozen? A Weather Forecast Ensemble** 180

20.6.2 **Fluctuations Especially with North-Westerly Currents** 181

20.7 **From “Wild Bunch” to Power Plant Network** 182

20.7.1 **Trans Europe Express: What a Future Offshore Grid Might Look Like** 182

20.7.2 **Orderly Cluster Formation** 183

20.7.3 **Offshore Clustering Is Both Easier and More Difficult** 184

20.7.4 **Over 70 Grid Calculations for a Four-Hour Forecast** 184

20.7.5 **Operational Management Strategies** 184

20.7.6 **Not the End, but a New Beginning: The Wind Farm Simulator** 185

20.8 **Outlook: Control System and Last Instance** 185

20.9 **Sources** 186

V Environment and Ecology

21	The most Important Environmental Project in a German Offshore Wind Farm	189
	<i>Anika Beiersdorf, Maria Boethling, Axel Binder, Kristin Blasche, Nico Nolte, Christian Dahlke, Copy edited by Björn Johnsen</i>	
21.1	How It all Began	190
21.2	The Go-Ahead for Knowledge	191
21.3	If You Don't Know What to Do Next, Organise a Workshop	191
21.4	The Results of the Environmental Research	192
21.4.1	Impacts on Pelagic Fish	192
21.4.2	Impacts on Demersal Fish and Crustaceans	192
21.4.3	Result: Merged and Standardised Environmental Database	194
21.4.4	The Claw, the Trawl Net and the Seabed	194
21.4.5	Gannets and Friends: The Impacts on Sea and Migratory Birds	195
21.4.6	Viewing and Evaluating Data on Seabirds	197
21.4.7	Porpoise and Friends: Impacts on Marine Mammals	198
21.4.8	Joint Evaluation of Data About Marine Mammals	199
21.4.9	Marine Mammals and Ecological Habitat Modelling	199
21.4.10	Piling and Operating Noise	199
21.4.11	Underwater Noise: New Measuring Specifications	199
21.4.12	International Publication	199
21.4.13	Standard Investigation Concept: Where It Goes from Here	200
21.5	The Most Relevant New Features in StUK	200
21.6	Sources	201
22	Much Hubble-Bubble About Nothing?	203
	<i>Raimund Rolfes, Jörg Rustemeier, Tanja Griefßmann, Text written by Björn Johnsen</i>	
22.1	Scaring off Porpoises and Soft Starts	204
22.2	Small Bubbles, Big Impact	205
22.3	Three Levels and One Curtain	206
22.4	It's the Current that Does It	207
22.5	There Is Need for Improvement	208
22.6	Sources	210
23	Like the Din in a University Canteen	211
	<i>Michael Benesch, Hermann van Radecke, Copy edited by Björn Johnsen</i>	
23.1	Measurements Virtually Only in the Baltic Sea to Date	212
23.2	Divers at Work	212
23.3	Wind and Waves Make It Possible: The Greater the Output, the Less the Noise	213
23.4	Distant Shipping in the Background	214
23.5	Offshore Piledriving Carries over here from 50 Kilometres	214
23.6	Hearing Damage Improbable	215
23.7	Sources	215

24	Out of Sight, out of Mind?	217
	<i>Gundula Hübner, Johannes Pohl, Copy edited by Björn Johnsen</i>	
24.1	Introduction	218
24.2	Intensive Surveys	218
24.3	2+2 Comparisons in the North and Baltic Seas.....	219
24.4	There Is Support, if	219
24.5	Safety of Shipping Desired	220
24.6	Problem Animals: Marine Mammals and Birds.....	220
24.7	Landscape, Sense of Home, Quality of Life.....	220
24.8	Reassuring Experiences After Start of Operation	222
24.9	Lack of Opportunities for Participation.....	223
24.10	World and Values After Fukushima	224
24.11	Conflict Avoidance and an Increase in Acceptance.....	224
24.12	Money Is Not Everything	225
24.13	What Do We Do During the Construction and Operational Phases?	225
24.14	Summary: Participation Processes in Large-Scale Infrastructure Projects	226
24.15	Sources	226
VI	Safety	
25	When the Nautilus Struggles During a Dive	229
	<i>Raimund Rolfes, Moritz Fricke, Tanja Griefsmann, Text written by Björn Johnsen</i>	
25.1	Finding Solutions for Two Totally Contradictory Goals.....	230
25.2	A Transponder Rarely Comes Alone	230
25.3	Between Sea and PC: Sound Absorbers and Simulations.....	231
25.4	Good Weather Is Something Else – Measurements at Sea State 4	232
25.5	The Fundamental Question on Alpha Ventus: What Do You Think About the Eco Assessment?	233
25.6	The “Seal Bell” Rings for Dinner at the Fishing Net	234
25.7	Short-Term Danger at the Foundation	234
25.8	Perfectly Normal Behaviour: Scarper, Stress, Avoid	234
25.9	Recommendations, for Others Also.....	234
25.10	Sources	235
26	A Bit too Much Salt of the Earth	237
	<i>Heiko Hinrichs, Thole Horstmann, Uta Kühne, Monika Mazur, Henry Seifert, Copy edited by Björn Johnsen</i>	
26.1	Look, Don’t Touch	238
26.2	Metal Plates Hung up Like Towels – to Rust	238
26.3	The Bremerhaven Salt Chamber	238
26.4	Swab Samples: Please Don’t Wipe the Microbes off	240
26.5	Temperature and Humidity in the Rotor Blade.....	241
26.6	Temperature and Humidity in the Nacelle	242
26.7	On the Trail of the Salt: The Detective that Never Slept	242
26.8	Automatic Measurement of Salt Deposits	243

26.9	Rearing Salt Crystals in the Lab	244
26.10	Rendezvous at the Old Oil Pier	244
26.11	Outlook	245
26.12	Sources	246
27	SOS on Offshore Platform Seven	247
	<i>Christine Carius, Christoph Jacob, Martin Schultz, Copy edited by Björn Johnsen</i>	
27.1	What Has Happened up to Now	248
27.2	In an Emergency: Nothing Works Without Communication	248
27.3	... And Nothing Works Without Wi-Fi!	248
27.4	Audiovisual System: The Injured Person Feels Safer	250
27.5	Prototype to Go: The TMBox	250
27.6	In Future an App Instead of an Applicator?	251
27.7	Sources	252

List of Authors

Dr. Matthias Baeßler

Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin
matthias.baessler@bam.de

Anika Beiersdorf

formerly Federal Maritime and Hydrographic
Agency (BSH)
Hamburg Port Authority (HPA)
Neuer Wandrahm 4
20457 Hamburg
anika.beiersdorf@hpa.hamburg.de

Volker Berkhout

Fraunhofer IWES
Königstor 59
34119 Kassel
volker.berkhout@iwes.fraunhofer.de

Dr. Michael Benesch

Rützenhagen 1
23795 Negernbötel
mben@gmx.de

Axel Binder

Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
axel.binder@bsh.de

Kristin Blasche

formerly Federal Maritime and Hydrographic
Agency (BSH)
Hamburg
Kristin.blasche@gmail.com

Dr. Maria Boethling

Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
maria.boethling@bsh.de

Dr. Lüder von Bremen

ForWind – University of Oldenburg
Ammerländer Heerstraße 136
26129 Oldenburg
lueder.von.bremen@forwind.de

Dr. Beatriz Cañadillas

UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
b.canadillas@dewi.de

Christine Carius

formerly Charité – Universitätsmedizin Berlin
carius@bwl.uni-kiel.de

Dr. Pablo Cuéllar

Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Christian Dahlke

formerly Federal Maritime and Hydrographic
Agency (BSH)
cd.dahlke@gmail.com

Prof. Stefan Emeis

Institute of Meteorology and Climate Research
Karlsruhe Institute of Technology
Kreuzackbahnstraße 19
82467 Garmisch-Partenkirchen
stefan.emeis@kit.edu

Stefan Faulstich

Fraunhofer IWES
Königstor 59
34119 Kassel
stefan.faulstich@iwes.fraunhofer.de

Dr. Richard Foreman

formerly UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
r.foreman@dewi.de

Dr. Moritz Fricke

Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
m.fricke@isd.uni-hannover.de

Steven Georgi

Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Dr. Tanja Grießmann

Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
t.griessmann@isd.uni-hannover.de

Dr. Gerrit Haake

formerly Adwen GmbH
gerrit.haake@gmx.de

Dr. Moritz Häckell

Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
m.haeckell@isd.uni-hannover.de

Berthold Hahn

Fraunhofer IWES
Königstor 59
34119 Kassel
berthold.hahn@iwes.fraunhofer.de

Wilhelm Heckmann

Offshore Wind Consultants (Aqualis) GmbH
Poststraße 33
20354 Hamburg
wilhelm.heckmann@owcltd.co.uk

Kai Herklotz

Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
kai.herklotz@bsh.de

Prof. Heiko Hinrichs

University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
hhinrichs@hs-bremerhaven.de

Dr. Annette Hofmann

Adwen GmbH
Am Lunedeich 156
27572 Bremerhaven
annette.hofmann@de.adwenoffshore.com

Thole Horstmann

University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
thole.horstmann@hs-bremerhaven.de

Prof. Gundula Hübner

Martin Luther University Halle-Wittenberg
Psychology Department
06099 Halle (Saale)
gundula.huebner@psych.uni-halle.de

Christoph Jacob

formerly Charité – Universitätsmedizin Berlin

Björn Johnsen

Windmedia
Querstraße 31a
30519 Hannover
johnsen@windmedia.de

Krassimire Karabeliov

Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Dr. Jan Kruse

Senvion GmbH
Überseering 10
22297 Hamburg
jan.kruse@senvion.com

Uta Kühne

University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
uta.kuehne@fk-wind.de

Marco Lewandowski

BIBA - Bremer Institut für Produktion und Logistik
GmbH
Hochschulring 20
28359 Bremen
lew@biba.uni-bremen.de

Hans-Peter Link

DNV GL
Sommerdeich 14b
25709 Kaiser-Wilhelm-Koog
hans-peter.link@dnvgl.com

Monika Mazur

Fraunhofer IWES
Am Seedeich 45
27572 Bremerhaven
monika.mazur@iwes.fraunhofer.de

Dr. Thomas Neumann

UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
t.neumann@dewi.de

Dr. Nico Nolte

Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
nico.nolte@bsh.de

Stephan Oelker

BIBA – Bremer Institut für Produktion und Logistik
GmbH
Hochschulring 20
28359 Bremen
oel@biba.uni-bremen.de

Dr. Johannes Pohl

Martin Luther University Halle-Wittenberg
Psychology Department
06099 Halle (Saale)
johannes.pohl@psych.uni-halle.de

Dr. Hermann van Radecke

Fachhochschule Flensburg
Kanzleistraße 91–93
24943 Flensburg
hermann.vanradecke@fh-flensburg.de

Dirk Reinhold

Senvion GmbH
Am Friedrichsbrunnen 2
24782 Büdelsdorf
dirk.reinhold@senvion.com

Prof. Raimund Rolfes

Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
r.rolfes@isd.uni-hannover.de

Jörg Rustemeier

Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
j.rustemeier@isd.uni-hannover.de

Dr. Werner Rücker

Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin
werner.ruecker@bam.de

Ingo Schlalos

SWMS Systemtechnik Ingenieurgesellschaft mbH
Donnerschwer Straße 4a
26123 Oldenburg
schlalos@swms.de

List of Authors

Dr. Martin Schultz

formerly Charité – Universitätsmedizin Berlin
Heart and Diabetes Center NRW
Institute for Applied Telemedicine
Georgstraße 11
32545 Bad Oeynhausen
mschultz@hdz-nrw.de

Prof. Henry Seifert

University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
hseifert@hs-bremerhaven.de

Sebastian Stock

Fraunhofer IWES
Königstor 59
34119 Kassel
sebastian.stock@iwes.fraunhofer.de

Prof. Klaus-Dieter Thoben

BIBA – Bremer Institut für Produktion und Logistik
GmbH
Hochschulring 20
28359 Bremen
tho@biba.uni-bremen.de

Dr. Arne Wessel

Fraunhofer IWES
Königstor 59
34119 Kassel
arne.wessel@iwes.fraunhofer.de

Construction, Operation, Measurement, Coordination

Chapter 1 **Metamorphoses of an Offshore Wind Farm – 3**
Björn Johnsen

Chapter 2 **Who, What, When, Why and Above
All – Where to? – 11**
Björn Johnsen

Chapter 3 **A Thousand Sensors, from the Blade Tip
to the Bottom of the Sea – 17**
*Kai Herklotz, Thomas Neumann, Wilhelm Heckmann,
Hans-Peter Link, Copy edited by Björn Johnson*

Metamorphoses of an Offshore Wind Farm

Planning, Construction and Operation of Germany's First Offshore Wind Farm and Test Field Alpha Ventus

Björn Johnsen

- 1.1 In the Beginning Was the Sea – 4
- 1.2 Prerequisites and Previous Experience – 5
- 1.3 Foundation Concepts: Something New on the Sea Bed – 5
- 1.4 Delayed Completion – 6
- 1.5 Installation, Logistics and Cabling – 7
- 1.6 Operation, Maintenance and Farm Control System – 7
- 1.7 Money and Its Usages – 8
- 1.8 Sources – 9

Project information: Planning, construction and operation of a 60 MW offshore wind farm 45 kilometres off the island of Borkum for test and research purposes

Project management:

DOTI – Deutsche Offshore-Testfeld- und Infrastruktur-GmbH & Co. KG

Wilfried Hube

1.1 In the Beginning Was the Sea

No experience of offshore wind turbines, not much chance of a profit, uncertain territory, and then off out onto the high seas. The first time anywhere in the world at such a great distance from land, in water depths of 30 metres, and a service life of 20 years. Faced with such an investment prospect any business would usually say “Thanks, but no thanks”. Luckily the discussions during the planning, construction and operation of Germany’s first offshore test field went much better – and finally the Alpha Ventus wind farm actually became reality under the leadership of Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG. Generally known as DOTI, this is a joint venture by energy suppliers EWE, E.ON and Vattenfall which realised Germany’s first offshore project in the North Sea and has been operating it ever since (■ Fig. 1.1). With 4,500 and more full load hours, Alpha Ventus is unparalleled anywhere in Europe. But first things first.

Peripheral Anecdote (I): Legal commuting between Hamburg, the capital and East Frisia

The start was made in East Frisia. In the autumn of 1999, the owner of a wind farm planning and design office, Ingo de Buhr, visited the Federal Maritime and Hydrographic Agency (BSH) in Hamburg to present his plans for the erection of the “Borkum West” wind farm. It was Germany’s first offshore wind farm project. There was not yet a legislative framework for offshore wind

farms, nor were there any proper wind measurements. EU-wide the use of an exclusive economic zone beyond the 12-sea-mile limit had only been in force for a few years. BSH lawyer Christian Dahlke created the legal framework for offshore wind farms quite quickly, for example with the “Standards for Environmental Impact Assessments”, introduced in 2002. There was resistance from residents of the island of Borkum, but backing and great plans from Berlin. In 2002 the federal government set a target of installing 500 megawatts of offshore wind power by the end of 2006, and “at least two to three thousand megawatts more by 2010”. At least three German wind turbine managers considered getting involved in offshore wind power. By the start of the new millennium planning was moving ahead at a pace, but the costs of construction were outstripping the budget. The banks were unwilling to risk the financing, insurers were unwilling to insure, manufacturers still had no offshore experience and, putting it diplomatically, there was a great deal of room for improvement as far as the grid operators’ inclination to provide the connection to the grid was concerned. For many of the players it was quite clear that the billion-euro offshore business was too expensive for conventional planning and design offices. Offshore, the standard wind farm size of 40 to 50 turbines quickly exceeded the billion-euro mark. Without the involvement of the major energy suppliers there was no way offshore could succeed – it needed an “icebreaker” to prove that offshore wind energy use does work. So the planned Borkum West wind farm went through a metamorphosis. The planning and design rights were transferred to a specially established foundation, the “Stiftung der deutschen Wirtschaft zur Nutzung und Erforschung der Windenergie auf See” (Offshore Wind Energy Foundation). In autumn 2005, just before the general election, the federal ministry provided its five million euros of starting capital. The Alpha Ventus test field with twelve turbines built by Adwen (then Areva) and Senvion (then REpower) went into planning.