MIDDELGRUNDEN 40 MW OFFSHORE WIND FARM DENMARK - LESSONS LEARNED

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ABSTRACT: The paper describes the model for public involvement, based on experience from offshore projects in Denmark and factors affecting the method of installation, the skills and resources required and the experience in shallow waters with strict requirements for environmental consideration when establishing an offshore wind farm. The paper is based on the experience gained during the establishment of the offshore wind farm Middelgrunden, 40 MW established 3.5 km outside Copenhagen harbour on shallow water (3-8 meters deep) in the autumn of 2000. It is concluded that although active public involvement is a time and resource requiring challenge, it is to be recommended as it may lead to mitigation of general protests, blocking or delaying projects, and increase future confidence, acceptance and support in relation to the coming offshore wind farms in Europe. The experiences from the planning of the project is summarized, and the perspectives for the future development of offshore wind power in Europe are drawn.
KEY WORDS: wind turbine, cooperative, economic, offshore, energy, environment, public awareness, renewable.

1 INTRODUCTION

In Denmark many people are involved in wind energy projects, approximately 150,000 families, due to environmental concerns and/or the possibility of receiving some financial benefits.

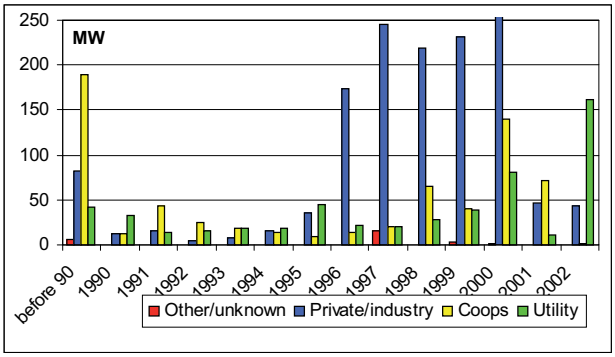

Figure 1 *Development in ownership of wind farms in Denmark MW installed power each year [13]*

The cooperatives, where mostly local people share expenses and income from a wind turbine, have played an important role, especially providing acceptance at a local level, where the possibility of resistance is otherwise high due to visual or noise impacts.

In general there is a broad acceptance to wind energy in Denmark – opinion polls result in at least 70% being in favour of wind energy, whereas about 5% are against.

Regarding offshore, the farms established in the 1990-ies at Vindeby and Tunø Knob are utility owned, whereas the Middelgrunden is owned 50% of the local utility and 50% of a cooperative.

The involvement of the public regarding Vindeby and Tunø was based basically on the information approach, whereas a much more active information and participation strategy was used and needed at Middelgrunden, as described below.

2 THE MIDDELGRUNDEN PROJECT

The Middelgrunden Wind Farm has a rated power of 40 MW and consists of 20 turbines each 2 MW. The farm was establish during year 2000 and is at that time the world's largest offshore wind farm. The farm is owned partly by the Copenhagen Utility and partly by a cooperative with 8,650 members. The farm delivers more than 3% of the power used in Copenhagen [5] and [6].

The wind farm is situated on a natural reef 3.5 km east of the Copenhagen harbour. The reef has for more than 200 years been used as dumpsite for harbour sludge and other contaminated waste. Special environmental concern has been taken and feasibility studies have been carried out [1], [2], [3], [4], [5] and [7].

Figure 2: *The Middelgrunden Wind Farm.*

An old dry dock of a former shipyard was used for casting the concrete gravity foundation. The foundation together with the lower section of the turbine tower, the transformer and switchgear were floated out to the site in the autumn of 2000. The abandoned shipyard was also used for assembling the rotor, which together with the upper section of the tower and the nacelle was floated out on a barge. For positioning of the turbine a jack up platform was used (see [6], [7] [16] and [19]).

Figure 3 *The location of the Middelgrunden Wind Farm 3.5 km east of Copenhagen harbour.*

Table I *Facts about the Middelgrunden Wind Farm [6] and [9]*

Power	40 MW
Hub height	64 meter
Rotor diameter	76 meter
Total height	102 meter
Foundation depth	4 to 8 meter
Foundation weight (dry)	1,800 tons
Wind speed at 50-m height	7.2 m/s
Guarantied/expected power output	89/100 GWh/y
Park efficiency	93 %.

Table II *Partners involved*

Owner 10 turbines north	Copenhagen Energy
Owner 10 turbines south	Middelgrunden Cooperative
Project management assisted by	SEAS, Wind Energy Center SPOK ApS (EMU)
Design	Møller & Grønborg
Structural design	Carl Bro as
Manufacturer of turbines	Bonus Energy A/S
Contractor, foundation including sea work	Monberg & Thorsen A/S & Pihl & Søn A/S
Contractor, sea cable	NKT Cable A/S
Switchgear and transformer	Siemens A/S

Table III *Budget of the wind farm, grid connection from land to the farm not included [7] and [8]*

The total investment in the project	**EUR (mill)**
Wind turbines	26.1
Foundations including changes after the tender to reduce the time on sea	9.9
Grid connection, off-shore	4.56
Design, advice and planning	2.15
Wind turbine cooperative	0.54
Other costs	1.61
Total	**44.9**

3 HISTORY AND IMPORTANCE OF THE COOPERATIVE

In 1996, the Copenhagen Environment and Energy Office (CEEO) took the initiative to organize the project, after the location of Middelgrunden had been pointed out as a potential site in the Danish Action Plan for Offshore Wind [10]. Together with CEEO a group of local people formed the Middelgrunden Wind Turbine Cooperative and a cooperation with Copenhagen Energy was established. As the Municipality of Copenhagen owns Copenhagen Energy, a close link to politicians was thereby also established. The locally based commitment, along with cooperation between the cooperative, the local utilities, and the municipality of Copenhagen, constituted a significant precondition for the development of the project.

The project was subject of a long and intensive hearing phase, as can be seen from table 4.

The original project dating back to 1997 consisted of 27 turbines placed in three rows. After the public hearing in 1997, where this layout was criticised, the farm layout was changed to a slightly curved line and the number of turbines had to be decreased to 20 [4], [11] and [12].

Table IV *Process of the establishment of Middelgrunden offshore wind farm [1], [5], [6], [7]*

Application on principal approval	September 1996
First public hearing, 27 turbines	June – Sep 1997
Second public hearing, 20 turbines	June – Sep 1998
Principal approval	May 1999
Third public hearing (Environmental Impact Assessment report)	July – Oct 1999
Final permit from Danish Energy Agency	December 1999
Contracts signed	December 1999
Construction initiated	March 2000
Casting concrete	April - July 2000
Starting work on seabed	May - June 2000
Placement of gravity foundations including the first 30 m section of the tower	October - November 2000
Placement of the sea cables between the turbines	November
Placement of the upper part of the turbine including rotor	November - December 2000
First turbines start production	December 2000
Commissioning	March 2001

The authorities raised a number of questions that were answered during the publicly funded pre-investigations. During the hearing in 1997 24 positive and 8 critical answers were received.

Behind these figures, a comprehensive information work is hidden, both in relation to relevant authorities and NGO's and in relation to the many future shareholders in the cooperative.

For instance, locals were worried about potential noise impact from the farm, but after a demonstration tour to a modern on-shore wind turbine, the locals were convinced that there would be no noise impact from the Middelgrunden turbines.

Information to the potential shareholders was in the beginning primarily carried out with the purpose of securing a sufficient number of pre-subscriptions. This turned out to be a success, and the interest of more than 10,000 local people was a proof of a strong local support, which could be useful in the approval phase.

A part of the shareholders got involved in the democratic hearing process, which was intended to create the foundation for authorities' approvals.

As an example the Danish Society for the Conservation of Nature at first decided to reject the proposed location, but through involvement of and information directed at the local committees of the society, this decision was later changed.

Figure 4 *The Middelgrunden "27 turbines in three rows" and "20 turbines in a curved line" from the beach at Kastrup [11] and [12]*

At the final hearing a large number of local groups and committees, not mentioning the several thousand shareholders, recommended and supported the project – only a relatively small group of yachtsmen, fishermen, individuals and politicians remained in opposition.

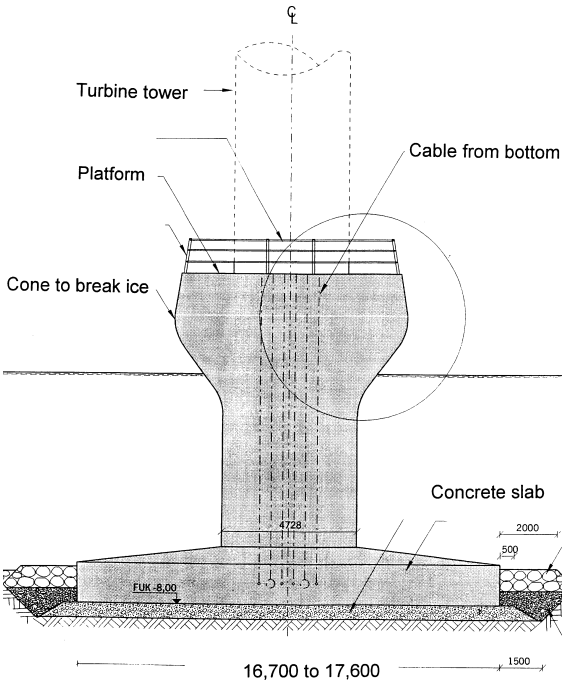

Figure 5 *The actual design of the concrete gravity foundation. The height of the total foundation is between 11.3 and 8 m. Measures in mm. [7] and [15]*

During and after the construction there has been surprisingly little resistance to the project, considering the visual impact from the large turbines, located just 2 – 3.5 km away from for instance a very popular recreational area – a beach - near Copenhagen. The reason for this lack of protest is believed to be the strong public involvement, both financially and in the planning phase.

4 THE UTILITY

In 1996 the Copenhagen Energy took the first step to investigate the feasibility of an offshore wind farm at Middelgrunden, too.

The Municipality of Copenhagen owns[1] the Copenhagen Energy. After 2 years of negotiations and overcoming political differences, a contract between the cooperative and utility was established in 1998.

The Wind Energy Centre at the utility SEAS acted as consultant for the Copenhagen Utility, and was heading the project organization for the establishment of the wind farm.

It is the evaluation that both parties (cooperative and utility) have gained from the arrangement. The Utility possesses the big organization for questions about technique, contractor work, etc. The wind cooperative has the knowledge from the private wind sector, with enthusiasm and commitment as well as better contacts with the public and the press. The locally based commitment, along with cooperation between the cooperative, the local utilities, and the municipality of Copenhagen, constituted a significant precondition for the development of the project. This cooperation has provided credibility to the project in relation to politicians and the public.

5 THE FINANCING OF THE COOPERATIVE

The cooperative's part consists of 40,500 shares. One share represents a production of 1,000 kWh/year, and is sold for 4,250 DKK (567 EUR). All shares were paid up front in order to follow the constitution of the cooperative.

By now, more than 8,650 people, primarily in the local area, have joined the cooperative. By October 2000, 100 % of the private shares were sold. The cooperative is the world's largest wind turbine cooperative. The project is the largest wind farm worldwide based on dual ownership and the largest offshore wind farm in the world when established.

Table V *Sales price of electricity delivered to the grid from the Middelgrunden Wind Farm [5]*

Year	**Fixed price**	**Added price for renewable energy**
	€/kWh	€/kWh
0-6	0.044	0.036
6-10	0.044	0.013
10-20	Market price	CO_2 bonus 0.013

In the beginning, only people from the municipal area could buy shares (equivalent to 1,000 kWh/year). In 1999, new regulation came into effect and all Danish people could buy shares. The newest development in year 2000 was that all people also outside Denmark could buy it within certain conditions. Today only about 100 shares are owned by people from outside Denmark.

Table VI *Key figures for production based on budget, interest rate 5% and 20 years lifetime, [5] and [8]*

Production price of electricity	0.046 €/kWh
Of which service	0.009 €/kWh
Investment/kW	1.14 €/kW
Yearly production	100,000 MWh

Table VII *Economy for a typical shareholder [5] and [8]*

Jensen family bought 1 share (1,000 kWh/year) Price of the share is 4,250 DKK (567 €) (172 mill DKK/40,500 shares = 4,250 DKK)	
Selling price of electricity	330 DKK
RE bonus (see table 5)	270 DKK

[1] In 2001 the Copenhagen Utility has merged with E2 Energi covering most of the energy production in the eastern part of Denmark.

Income/year	600 DKK
Maintenance cost	-70 DKK
Net income/year	530 DKK
Rate 530/4,250	12.5%
Simple pay back time	8 years
Calculated lifetime	20 years
5% yearly depreciation	213 DKK/year
Income after depreciation	318 DKK/y
Rate after depreciation	7.5%

Table VIII *Financing of the project [5] and [8]*

When	Activity	Funding M €	
		Public	Project
12-1996	Information prospect	0.01	
03-1997	1st feasibility Killer assumptions	0.15	
05-1997	Cooperative formed Advertising 7 €/share		0.13
08-1997	1st public hearing Visualisation 1	0.04	
11-1997	2nd feasibility - engineering, design - soil investigation	0.40	
08-1998	2nd public hearing - visualisation 2	0.05	
01-1999	Pre-qualification		0
05-1999	Planning permission	0.01	
06-1999	Detailed Project		0.27
07-1999	Environmental Impact Assessment	0.07	
08-1999	Soil investigation CPT		0.06
10-1999	Tender		0.12
11-1999	2 boreholes		0.05
11-1999	25 % Payment shares		4.3 *
12-1999	Permission		0.01
12-1999	Contact contractors		5.0 *
09-2000	100 % Payment shares		17.2 *

Under financed * 50 % total cost of project
Number of shares is based on 50 % of 81,000 MWh = 90 % of 89,000 MWh = guarantied production.

Figure 6: *A safe access to the foundation is essential when the waves and current are moving the ship.*

6 OFFSHORE COMPARED TO ONSHORE WIND FARMS

The main differences to onshore-based wind farms are:

- The preparation of the seabed for the foundation.
- The difficulties getting access to the turbines.
- The establishment of the submarine cables.
- The high voltage equipment situated in the tower.
- The lower turbulence of the wind offshore

In the following the observations form the installation of the base structure, sea cable and turbines are described with special attention to these differences.

7 THE INSTALLATION OF SUPPORT STRUCTURE, SUBMARINE CABLES AND TURBINES

7.1 Positioning

The floating of the gravity support structure including the lower section of the tower worked out satisfactory. Careful estimation of low tide was necessary, as there at a time was only 10 to 20 cm between the concrete slab and the seabed. The work was carried out day and night depending of the weather forecast. The positioning in horizontal direction was far within the tolerances specified. The vertical inclination of the tower was better than the requested accuracy. The special measures to cope with too high deviations in inclination were not activated.

Figure 7: *The floating crane with a foundation and the lower part of the tower at the site just before installation.*

7.2 Cables

The establishment of the submarine cables was carried out without any difficulties using a special build vessel from NKT Cables. The relatively shallow water and good weather conditions contributed to that.

The work within the tower separating the marine reinforcement from the core of the stiff cables turned out to be much more complicated than expected because of the narrow space.

The contractors working with the establishment of erosion protection damaged the cables tree times, even though it was a simple sea operation of a well-proven type.

7.3 Turbines

The use of a jack-up for placing the upper tower section, the nacelle and the rotor was necessary in order to secure a solid work platform for the 80-meter crane [7].

The work turned out to proceed much faster than feared. A record of 18 hours for completing two turbines was obtained.

8 THE OPERATIONS AT SEA

8.1 Divers

The bottleneck of the project was for a long period the access to divers. Almost all divers available from the eastern part of Denmark were activated during the peak period working with:

- Placing of cables and pull-up of cables in the tower
- Digging for the foundation and cable trench
- Placement and compaction of rock cushion
- Levelling of compacted rock cushion
- Placement of foundation caisson
- Removal of block for lifting operations

8.2 Planning

Carefully planning day-by-day was necessary in order to avoid that seabed operations upstream resulted in impossible working conditions downstream caused by particles in the water. Also the weather situation had to be taken into account.

After installation of the turbines up to 38 people coming from different companies were working every day on the different turbines. People were often shifting between turbines during the day. To secure the best and most safe working conditions, two persons were dedicated only to coordinate these tasks.

9 THE TIME SCHEDULE

In December 1999 the contracts with the contractors were signed. New rules just introduced for the wholesale price of power from renewable energy resulted in a very narrow timetable for the decisions connected to the start up of the project. The short planning time resulted in extra costs and special precautions not necessary for a future project of the similar kind with more time available for planning, but still within the budget.

The type and size of the turbine itself influenced the design of the support structure, the construction method and the establishment of the connection to the submarine cables.

The use of a larger floating crane turned out to give opportunity to revise the way of the total installation in a positive way. The larger capacity allowed the lower tower section including switchgear, transformer and control equipment to be established in the dry dock. The lower section of the tower already placed on the foundation allowed thereafter an effective way of pulling up the submarine cables into the tower as soon as the foundation was placed on its final site.

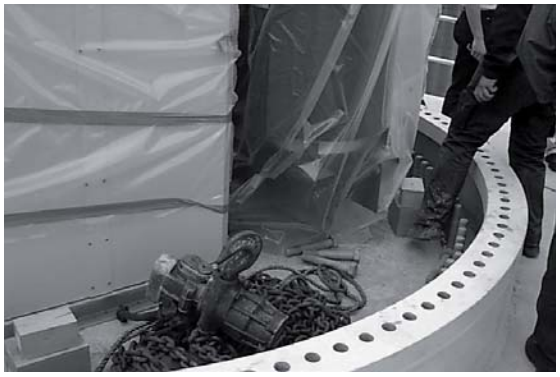

Figure 8: *The switchgear and transformer on top of the concrete foundation ready for placement of the tower.*

The first turbine started production at the end of December 2000 and the last at March 6, 2001. The total delay compared to the original timetable was 2 to 3 months. The reason for the delay was:

- More difficult seabed preparation than expected by the contractor, especially the compaction of the rock cushion
- 3 accidents with damages of the submarine sea cable
- Delay caused by the weather condition as the building period was prolonged to the winter season
- Longer time for the work at the turbines with the final connection to the grid than expected.

If the lower section of the tower had not been established in the dry dock, a much larger delay would have appeared.

10 THE PRODUCTION THE FIRST 1½ YEAR

The total power produced after 18 months of production is 68.6 GWh for the first 12 month and 68.6 GWh for the following 6 month. The farm has not been producing regularly during all 18 months as many small corrections have been carried out and 7 transformers and some of the switch gears have been changed. Further on the first 12 month were a very bad year for wind producers, as the wind intensity was only 80% of normal. The production yield can bee judged in the following way:

- The power curve shows 5,7% better performance than guaranteed (see figure 9).
- The power produced compared with the expected value of eastern Denmark is about 20% higher. This is following the tendency known from the Lynetten Wind Farm situated at the Copenhagen harbour.
- The shadow effect is as expected considerable with wind directly from north or south.
- The total loss of production caused by different failures the first year is 1-2% of the yearly production.

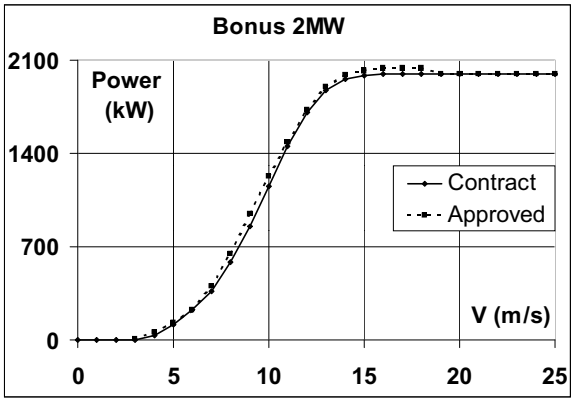

Figure 9: *Power curve for the 2 MW turbines based on 1½ year production. Production figures can be found on www.middelgrund.com. The information is updated every10 minutes*

11 LESSONS LEARNED

During the approval process, authorities raised a number of questions, that were answered through the carefully planned pre-investigations.

Dialogues with many kinds of interest groups, CEEO and the Middelgrunden Wind Turbine Cooperation, with its 8,650 members, generated a widespread understanding for and social acceptance of the chosen location and layout of the farm.

Locally based commitment and cooperation between the cooperative, the local utility, and the municipality of Copenhagen has been a significant precondition for the development of the project.

This cooperation has provided credibility to the project in relation to politicians, press, public etc. The municipality's role in the project has mostly been political, through the local

parliament commitment to the project as such, and through the preparation of the terms of collaboration between the utility and the cooperative.

The lessons learned of more technical kind are:

- The turbine tender has to be conducted before the foundation in order to avoid changes in the detailing if possible
- Special development is needed for placing and compaction of the rock cushion
- All operations have to be tested in advance - also the ones looking simple, as all operations of the standard type onshore are complicated offshore
- Carry out as many operations onshore as possible
- Installation of the sea cables offshore in the turbine tower seams to give large delay
- The dry transformer technology combined with switch gear seams not to be mature technology
- Transport of people to the turbines offshore has to be organized very carefully
- The use of divers seems to be a bottleneck
- Logistic planning is a must for keeping the time schedule
- Onshore 690 V experience can not be transferred to cables at 30 kV, as special safety is required
- Successive starting up of the production seems easy, but gives problems of many kinds
- Moist in the turbine tower was higher than expected before turbines came into operation´.

12 FUTURE OFFSHORE WIND PROJECTS IN DENMARK

Currently two private projects are planned, along with the five 150 MW demonstration projects [10]. Two of the 150 MW projects: Horn Rev and Nysted (Rødsand) are under establishment.

Of the two private projects, the one at Grenå is owned by a private developer and has been delayed due to much local resistance.

The other private project, the 23 MW project at Samsø (10 turbines), is owned by shareholders, consisting of local people and neighbouring municipalities. The farm will be established in the autumn of 2002, and because of the direct public involvement in the preplanning phase and the financial participation, the project has to date not been the focus of any major protests.

The coming three 150 MW offshore demonstration farms were intended to be utility owned, but as the utilities have seen the advantages of public involvement, they have agreed upon a plan drawn up by the Danish Association of Turbine Owners, including public financial participation. This agreement however has not been politically approved yet, and the Government has recently postponed the time for the establishment of the farms as Denmark already today has reached the goal for renewable energy based power for the year 2005.

13 RECOMMENDATIONS RELATED TO PUBLIC ACCEPTANCE

An open public dialogue already from the very beginning of a planning phase is crucial for achieving social acceptance – and the social acceptance on the other hand may influence political decisions.

Direct public involvement, e.g. the cooperative ownership model, is an important mean for social and political acceptance, but may influence strongly on decisions taken during the planning phase, which must be accounted for in the pre-planning phase as even minor deviations in the work at sea have a disproportional large effect on the time schedule.

There is today no clear overview on the results of different strategies for public involvement and conflict management. This is a subject that deserves to be studied in more detail, through a monitoring programme focussing on public acceptance before and after the installation of an offshore wind farm in relation to the degree of public involvement and active conflict management [17].

The future large deployment of offshore wind in Europe where the increase within 5-10 years will be 50 to 100 times the installed capacity of today [14] and [18] calls for intensive work with different models for public acceptance. Cooperative ownership has in Denmark proved to be one successful model.

14 ACKNOWLEDGMENT

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The Grenå project www.worldwidewind.com

Figure 10: *Screen dump of the Middelgrunden production March 6, 2000: www.middelgrund.com*