Experiences from Middelgrunden 40 MW Offshore Wind Farm

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1 ABSTRACT:

The paper describes the experiences from Middelgrunden Offshore Wind Farm. Middelgrunden was established on a natural reef with 3 to 8 metres water depth, 3.5km outside Copenhagen harbour, in the autumn of 2000. The offshore wind farm consists of twenty 2 MW turbines from Bonus Energy, now Siemens Windpower, and is owned 50% by Energi E2 and 50% by The Middelgrunden Wind Turbine Cooperative with 8,553 members. It is the largest wind farm in the world based on cooperative ownership.

The paper also describes the model for public involvement, based on experience from offshore projects in Denmark. 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.

Key words: Landmark, Copenhagen, Cooperative, Ownership, environment, public awareness, Cost, Operation, Offshore, Wind Farm, Production, Service, Maintenance, Transformer, Lesson learned.

2 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.

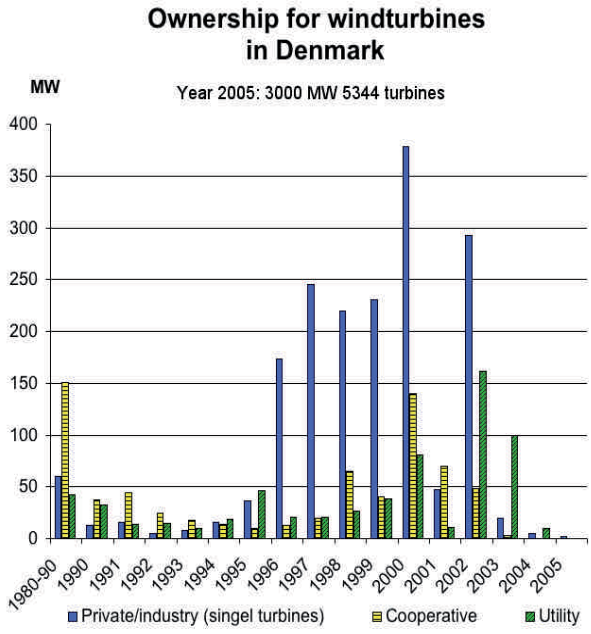

Figure 1 *Development in ownership of wind farms in Denmark MW installed power each year [13]*

In a cooperative investors, mostly local people, share expenses and income from a wind project. Cooperatives have played an important role, especially regarding local acceptance of wind developments, 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 more turbines in Denmark, whereas about 7% are against more turbines in Denmark [19].

Regarding offshore, the farms established at Vindeby, Tunoe Knob, Horns Rev and Nysted are utility owned, whereas Samsoe (22 MW) is owned by the local people and the Middelgrunden is owned 50% by the local utility and 50% by a cooperative.

The involvement of the public regarding the utility owned wind farms 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.

3 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 was at the time the world's largest offshore wind farm. The farm is owned partly by the utility Energi E2 and partly by a cooperative with 8,553 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 3.5km 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].

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] and [16]).

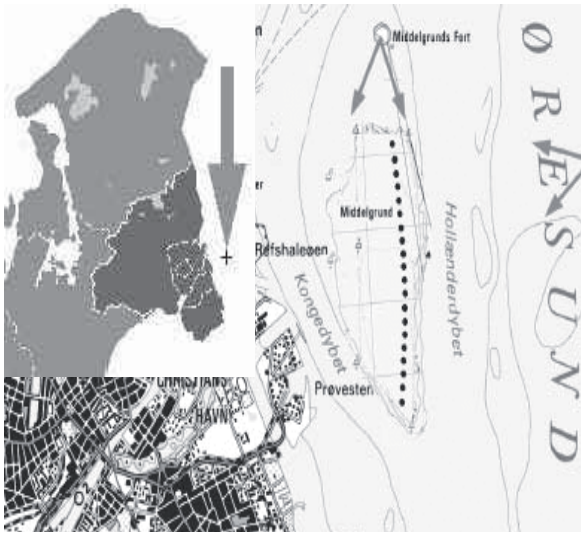

Figure 2 *The location of the Middelgrunden Offshore Wind Farm east of Copenhagen harbour.*

Figure 3: *The Middelgrunden Offshore Wind Farm.*

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

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

4 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[1] 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.

[1] Copenhagen Energy is the local utility. CE was partner in Middelgrunden Offshore Wind Farm at the time of establishment. Their part of the project has later been taken over by Energi E2.

Table II *Partners involved*

Owner 10 turbines north	Energi E2
Owner 10 turbines south	Middelgrunden Cooperative
Organising cooperative	Copenhagen Enviroment and Energy Office, CEEO
Project management assisted by	SEAS, Wind Energy Center SPOK ApS (EMU)
Design	Moeller & Groenborg
Structural design	Carl Bro as
Manufacturer of turbines	Bonus Energy A/S
Contractor, foundation including sea work	Monberg & Thorsen A/S & Pihl & Soen A/S
Contractor, sea cable	NKT Cable A/S
Switchgear and transformer	Siemens A/S

Table III. *Invested capital to construct the wind farm in 2000-01. Grid connection from land to the farm is not included. [20]*

The total investment in the wind farm	**EUR (mill)**
Wind turbines	26.68
Foundations, including changes after the tender to reduce the time on sea	12.94
Grid connection, off-shore	4.51
Design, advice and planning	2.98
Wind turbine cooperative	0.80
Other costs	0,64
Total	**48.55**

Table IV *Process of the establishment of Middelgrunden Offshore Wind Farm [1], [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 Authority	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 30m 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 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].

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" seen 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.

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 – 3.5km 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.

Now in 2005, after living next to the wind farm for 4 years, it is our opinion that the public and most people living in Copenhagen, in a positive sense, has accepted the wind farm.

International Herald Tribune wrote this summery in September 2003:

"COPENHAGEN Looking out to sea from this city's picturesque harbor, a wall of 70-meter windmills dominates the horizon with rotors silently spinning in the glinting sunshine as sailboats and fishing trawlers glide past.

For most Danes, these towering turbines are anything but an eyesore, and anything but a threat to the environment. In fact, they are featured on postcards and proclaimed attractions by tour guides on ferry boats. They are the pride of the local Greenpeace office, which even owns shares in the project.

Here, the windmills are seen as a graceful gateway to a historic harbor and a proud symbol for an environmentally conscious country that has put itself at the cutting edge of one of Europe's fastest growing energy sectors: wind power.

Danish wind-energy advocates say that the success of that industry, now providing 20 percent of Denmark's total power, was achieved by making the offshore wind farm projects a kind of public trust, with careful attention to the concerns of environmentalists and the local community.

Since the 1970's, the Danish government has promoted the industry through tax incentives and subsidies, enabling it to grow steadily.

Perhaps the biggest breakthrough was the development of the Middelgrunden Offshore Wind Farm Cooperative, the first large project lying less than three kilometers, or two miles, off the beautiful harbor of Copenhagen. Twenty turbines, each producing two megawatts of power, wrap themselves around the entryway to the harbor and provide energy for 40,000 or so households."

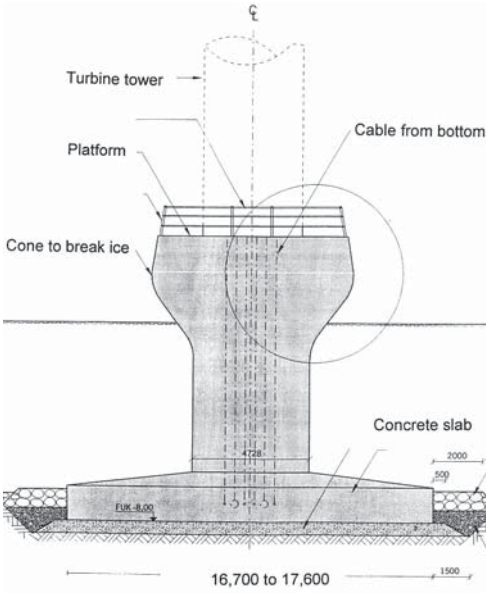

Figure 5 *The actual design of the concrete gravity foundation. The height of the total foundation is between 11.3 and 8m. Measures in mm. [7] and [15]*

5 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[2] 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

[2] In 2001 the Copenhagen Utility has merged with SK-Energi covering most of the energy production in the eastern part of Denmark. In 2005 this part was taken over by Energi E2.

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.

6 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 was 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 8,500 people, primarily in the local area, are members of the cooperative. By October 2000, 100 % of the private shares were sold. The cooperative is the world's largest wind turbine cooperative.

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

Year	Fixed price	Added price for renewable energy
	EUR/kWh	EUR/kWh
0-6	0.044	0.036
6-10	0.044	0.013 *
10-25	Market price	0.013 *

* CO_2 tax refund

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 latest 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 *Economy for a typical shareholder [5] and [8]*

Jensen family bought 1 share (1,000 kWh/year) Price of the share 4,250 DKK (172 mill DKK/40,500 shares = 4,250 DKK)	
Selling price of electricity	330 DKK
RE certificate (max, see table 5)	270 DKK
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	212.50 DKK/year
Income after depreciation	317.50 DKK/yr
Rate after depreciation	7.5%

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

Production price of electricity	0.046 EUR/kWh
of which service	0.009 EUR/kWh
Investment/kW	1.14 EUR/kW
Yearly production	89,000,000 kWh

7 THE PRODUCTION

The total power produced by the 40 MW wind farm after 4 years and 2 month is 400 GWh. The production yield can bee judged in the following way:

- The power produced is about 6.5% more than the expected budget of 89 GWH/year.
- The power curve shows 5.7% better performance than guaranteed (see figure 6).
- The wind farm has lost 13 transformers that short-circuited and burnt out. The production loss due to this is approximately 2.2% of the total production in the period up to now.
- The shadow effect is as expected considerable with wind directly from north or south.

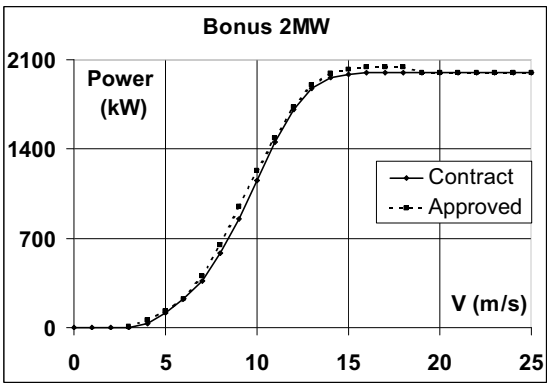

Figure 6: *Power curve for the 2 MW turbines. Production figures can be found on www.middelgrund.com. The information is updated every 10 minutes*

8 AVAILABILITY

Year	2001	2002	2003	2004
Availability of turbine (%)	97.3	98.8	98.1	98.7
Total availability incl. 30 kV grid (%)	85.4	96.4	95.9	95.6

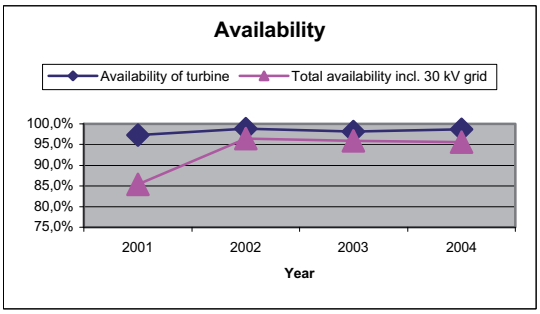

Figure 7: *Availability of the ten turbines owned by the Cooperativ.*

9 OPERATION AND MAINTENANCE

The turbines are serviced twice a year, whereas the electrical system (30kV) is only inspected once a year and maintained every second year. We have a service contract on the turbines with the turbine manufacturer and for the 30 kV grid with Copenhagen Energy[3].

[3] Since December 2004 with Eltel Networks Corporation OY, who bought KE partner, the division of Copenhagen Energy holding the contract.

Figure 8: *The distance between the posts in the fence has been too large creating vibrations caused by the wind. The repair is simple.*

Daily maintenance is carried out by the administration (CEEO). It includes:

- Checking the access ladder used by minor boats for damages, which are caused by ice or collision with the larger service boats.
- Service and maintenance of the drainage system for water condensed in the moist control equipment.
- Repair of cracks in the foundation rails.
- Repair of joints between tower and foundation.
- Checking the rescue equipment and the warning lights on top of the turbines.

The drainage system has not been working proberly, as it blocked from the beginning and it seems like the moist production is larger than anticipated (difficult to remember closing the door). Therefore we are considering changing the condenser to a larger size and replacing the drainage canal with a direct outlet from the moist condenser.

After the construction not all turned out as expected resulting in a need for replacement and inspections:

- The turbine has been modified in many places, e.g. cooling system, warning lights, internal power cables, greasing system, and the upper part of the tower has been reinforced. The work has been carried out by Bonus Energy, now Siemens, under the guarantee.
- The crack widths in the concrete caused by too high temperature differences during curing of the concrete has been monitored.
- The elevation of two towers placed on extra thick rock cushion are checked.
- The performance of repaired concrete, which surface was damaged during installation at sea, has been inspected.
- The corrosion development between the tower and the foundation is followed. The inner joint has been removed and the outer joint has been replaced.
- The aluminium rails around the tower has been checked and repaired. It is too slender and therefore subject to cracking caused by vibrations generated by the wind.

In the 30 kV system problems have arisen on:

- Switchgear defects.
- Breakdown of dry transformer

Table VIII *Key figures for operation and maintenance based on figures from 2003 and 2004 [22]*

Cost	EUR/kWh
Service on turbines	0.0041
Service control, daily maintenance, service on 30 kV power system	0.0012
Insurance	0.0026
Electricity consumption	0.0003
Total	0.0082

Three service teams are in action, since it has not been possible to obtain a unit contract. Fortunately the cooperation between Bonus and the administrator is excellent, which reduces the down time of the wind farm and reduces the costs of service boats. But there is no doubt that a saving could be obtained, if one company instead of three could organize all maintenance.

Figure 9: *The access ladders for smaller boats are damaged after winters with ice. A special weak link is build into the ladder in order to limit the damage.*

10 LESSONS LEARNED – EQUIPMENT/DESIGN

Many smaller improvements and changes have been introduced by the turbine manufacturer Bonus after installation. All on their expense and respecting that we don't like to loose production. We see that as a natural consequence of being the very first larger offshore wind farm, so the turbines still were partly based on onshore experience.

The switchgears seem to crack slowly. Cracks have developed in three of the units. Siemens has offered to replace all switchgears, but it will cause a lot of down time. The operation takes many days. And since the turbines are serial-connected, it means that all turbines, after the turbine under repair will be out of operations as well.

The monitoring system receives signals reporting faults on the 30 kV grid system about once a month. Some of these are "ghost" signals. As the operator has to stop the turbines each time to see if it is a real problem, we are loosing production. This problem still needs to be solved.

There is a pending court case on the short circuit of 13 transformers, which therefore can not be commented here. Though we will mention that three floors inside the tower have to be separated before the transformer can leave the tower. In order to reduce the down time many inventions have been made; like using alternative teams and finding other boats and cranes than usually used for this kind of operation.

The administration has been able to reduce the time for replacement to 6-8 working days. The total price of replacing a transformer is approx. 75,000 Euro.

Figure 10: *Transformer passing the door in the tower.*

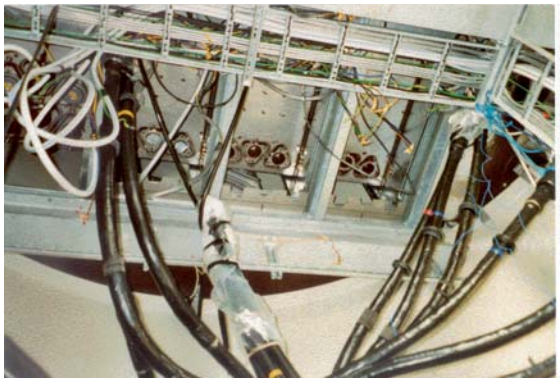

Figure 11: *Cracks have developed, where the cables are entering the switchgear*

11 ENVIRONMENT UPDATE

Figure 12: *The recovery of eelgrass after the construction has not been a problem .*

In year 2003, three years after commissioning of the wind farm, the key parameters from the environmental surveys and investigations carried out before and during construction was analysed by Hedeselskabet [21]. The two main indicators for the aquatic environment on the site are eelgrass and shell fish. The report concludes that the construction of the wind farm did not have any significant influence on the marine vegetation in the area. Already during installation of the turbines we have seen a beginning recovery of the eelgrass. The follow up investigation showed an almost 100% recovery. A good indicator is that the fishermen have returned and the site is attractive for them.

Figure 12: *Fishermen have returned and are fishing as before the construction of the wind farm.*

12 LESSONS LEARNED FROM PLANNING

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 Cooperative with its 8,553 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.

Figure14: *The floating crane with a foundation and the lower part of the tower at the site just before placing*

13 CONCLUSIONS

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.

Figure 15: *500 members of the cooperative visited their turbine on open-house day in June 2005.*

Figure 16: *Members of the cooperative participating in the annual meeting.*

14 ACKNOWLEDGMENT

The extensive pre-study of the Middelgrunden wind farm project has only been possible because of support from the Danish Energy Agency under the special scheme supporting private cooperatives to participate in the development of offshore wind farms.

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Figure 17: *Screen dump of the Middelgrunden production March 6, 2000: www.middelgrund.com*