

**WIND ENERGY TECHNOLOGY**

**ETC ENERGY**

## Introduction to Wind Energy

Gerrit Jacobs

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Jakarta  
Indonesia

Training Course on Renewable Energy Part II - MEMR  
**CASINDO**

## Introduction to Wind Energy

**ETC**

This presentation uses material from the training course "The implementation of Wind Energy" organized by ECN and Arrakis, which was held at ECN, the Netherlands from 1992 to 2003.

This presentation is intended for educational purposes and should by no means used commercially.

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## Introduction to Wind Energy

**ETC**

- Historical development
- Wind as an energy source
- Working principle of the rotor
- Energy production
- Working parameters
- Functional breakdown
- Structural aspects
- Offshore applications
- Environment - planning
- Market and economy


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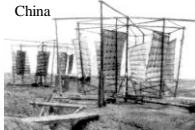
## Historical development

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### First applications: 600 - 1500



Persia (6th century AD)



China



Western Europe (15th century)



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## Historical development

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### First developments of the horizontal axis windmill: 1500 - 1900



La Cour, Askov (DK):  
First electricity generating wind turbine (1885)

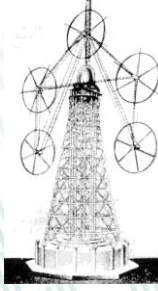
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## Historical development

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### First modern application: electricity production 1930 - 1945




D: Honnef (1932)



UDSSR: Baklava (1931)



USA: Grandpa's Knob (1941)



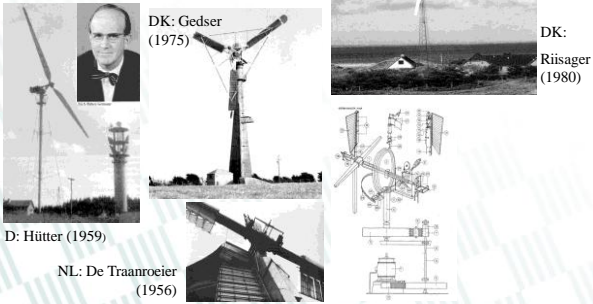
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## Historical development

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### Continued development of electricity producing turbines: 1950 - 1980



DK: Gedser (1975)

DK: Riisager (1980)

D: Hütter (1959)

NL: De Traanrooier (1956)

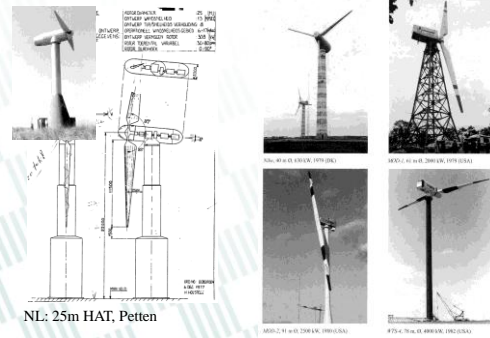
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## Historical development

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### Modern developments: 1980 - 1985



NL: 25m HAT, Petten

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## Historical development

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### Modern developments: 1980 - 1990



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## Historical development

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### Modern developments: 1990 - present



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## Introduction to Wind Energy

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## Wind as an energy source

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### Renewable energy potential



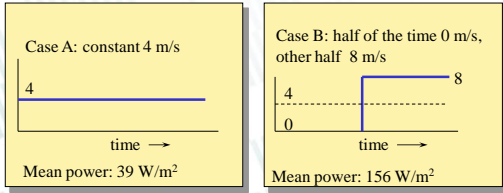
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## Wind as an energy source

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- The (annual) mean power depends on the **frequency distribution** of the wind speeds and is larger than the instantaneous power at the (annual) mean wind speed.
- Example: mean wind speed = 4 m/s



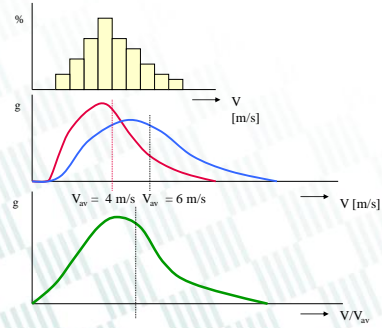
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## Wind as an energy source

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### Wind speed distribution

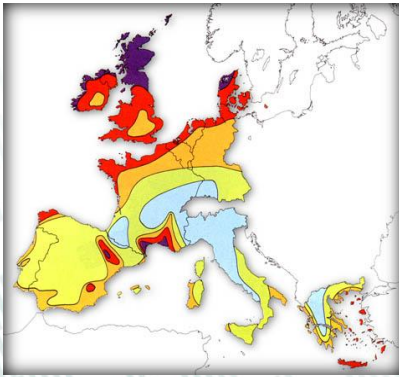


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## Wind as an energy source

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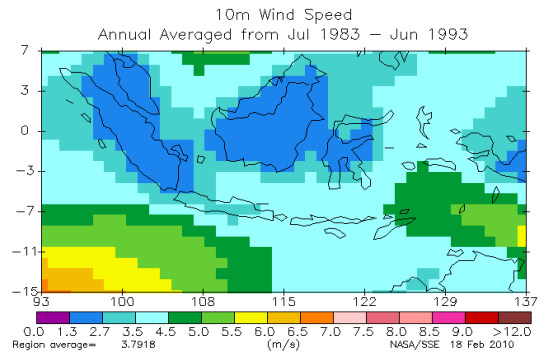


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## Wind as an energy source

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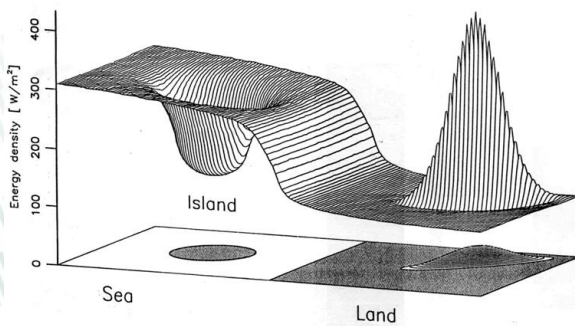
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## Wind as an energy source

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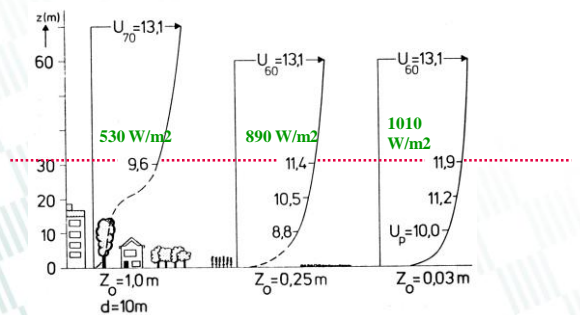
### Variation in wind resource



## Wind as an energy source

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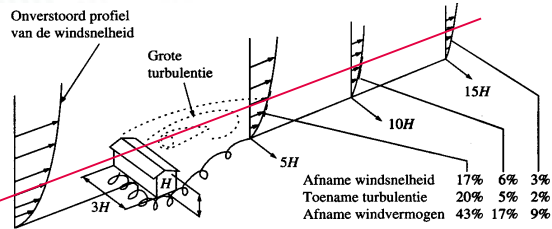
### Vertical gradient



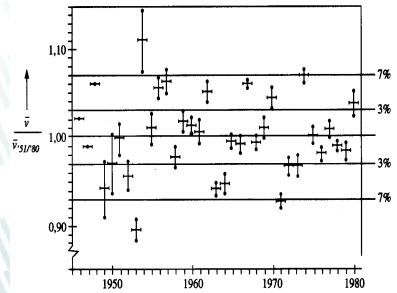
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Wind reduction factors



Annual variation of wind availability

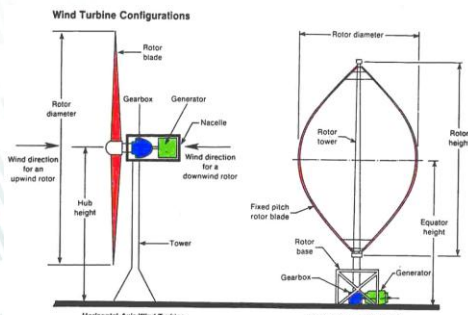


- Historical development
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Types: Horizontal axis & vertical axis machines

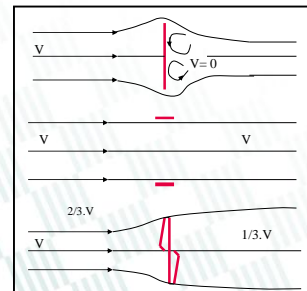


Types: Horizontal axis & vertical axis machines



Power output wind turbines

General operation of a rotor in free air

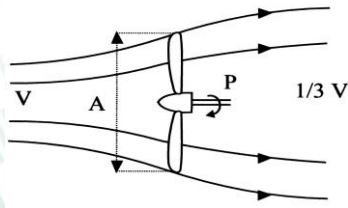


(Mass flow \* slowing of windspeed) should be maximum

## Working principle of the rotor

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### Betz limit



$$P = 1/2 \rho \cdot C_p \cdot V^3 \cdot A$$

$$C_p \leq 16/27$$

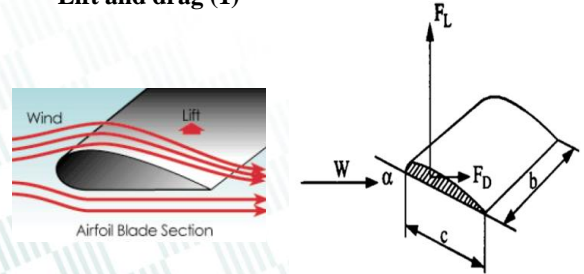


Mr. Betz

## Working principle of the rotor

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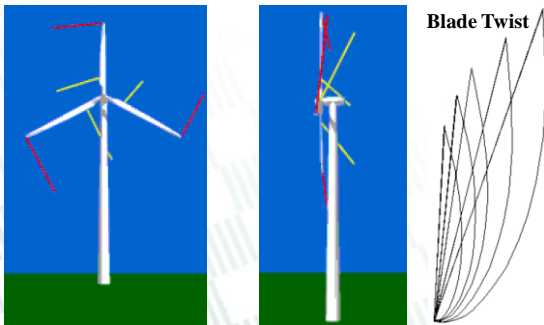
### Lift and drag (1)



## Working principle of the rotor

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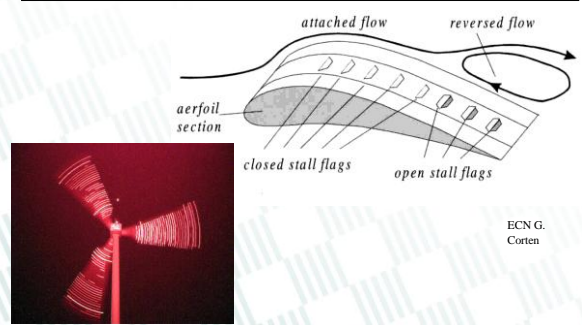
### Relative windspeeds at tip an 1/4 from hub



## Working principle of the rotor

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### Stall flags diagnosis

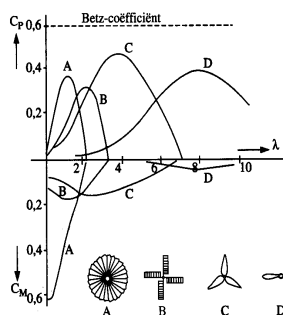


ECN G. Corten

## Working principle of the rotor

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### Various rotor types



The maximum value of  $C_p$  is more or less independent from  $\lambda$ . The value of  $C_p$  max varies between 0.35 - 0.5 for values of  $\lambda$  between 1 - 10. Therefore the maximum achievable power  $P = M \Omega$  is more or less constant for different values of  $\lambda$ .



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### Energy production

**Yield pattern (2)**

①  $\dot{P}_w = 0,36 v^3 A$

②  $\dot{P}_w = 0,29 v^3 A$

③  $\dot{P}_w = 0,20 v^3 A$

④  $\dot{P}_w = 0,10 v^3 A$

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### Working principle of the rotor

**Power curve Whisper**

2.1 m diameter 100

2.7 m diameter 200

**Performance Curves**

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### Introduction to Wind Energy

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### Working parameters

**Parameters**

- Yield factor  $P = a \cdot V^3$  [W/m<sup>2</sup>]
- Capacity factor  $F = E / (P_R \cdot 8760)$
- Availability  $T / 8760$

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### Working parameters

**Yield factor**

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### Working parameters

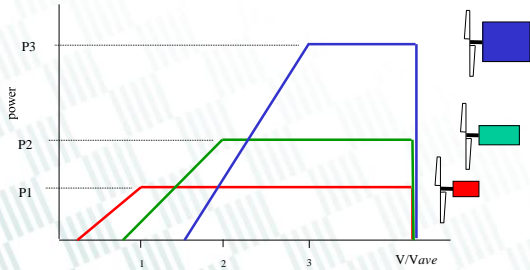
**Wind power**

$P = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot V^3$

Mr. Betz

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Wind turbine power curves



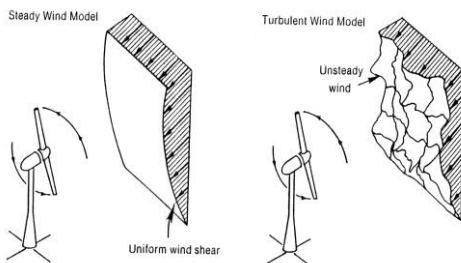
- Historical development
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- Failure protection; n, P, V, safe failure control
- Power output and speed control
- Vibration prevention
- Turbine rotation
- Speed reduction

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Development of rotor models



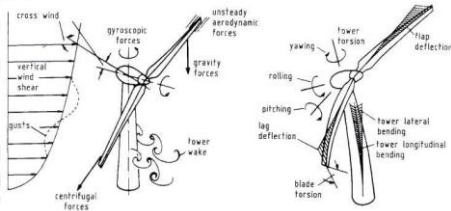
Loads

- Dynamic loads
- Many excitations and response modes
- Upscaling:
  - mass  $\sim (D \times D \times D)$
  - area  $\sim (D \times D)$
  - stress  $\sim D$

## Structural aspects

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### Dynamic loads



- Dynamic loads
- Many excitations and response modes

## Structural aspects

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### Wind turbine design of the future ?

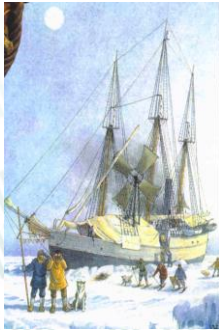


- Stream lined self rotating tower
- Flexible rotor blades
- Variable speed control system with direct driven generator
- Passive aerodynamic control and failure protection

## Structural aspects

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### Wind turbine of the future



Fram 1895, Roald Amundsen

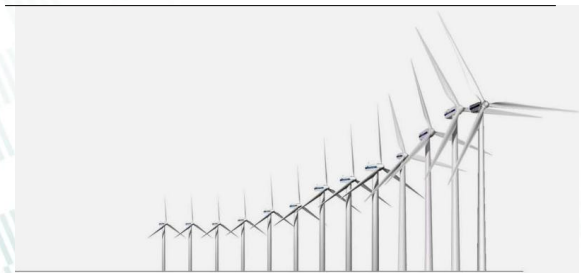
Back to the future:

- Offshore
- Autonomous system
- Extreme external conditions
- Variable speed
- Flexible rotor concept

## Structural aspects

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### Trend in wind turbines size

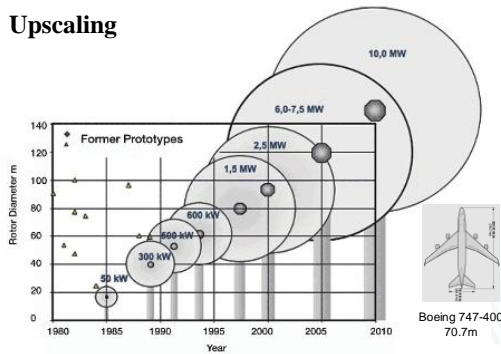


Product/Rotor diameter (m)	V15	V17	V19	V20	V25	V27	V39	V44	V47	V52	V66	V80	V90
Year of installation	1981	1984	1986	1987	1988	1989	1991	1995	1997	2000	1999	2000	2002
Capacity (kW)	55	75	90	100	200	225	500	600	660	850	1750	2000	3000
WWh/year	217	265	301	346	481	647	1304	1581	1947	2530	4705	6768	9152

## Structural aspects

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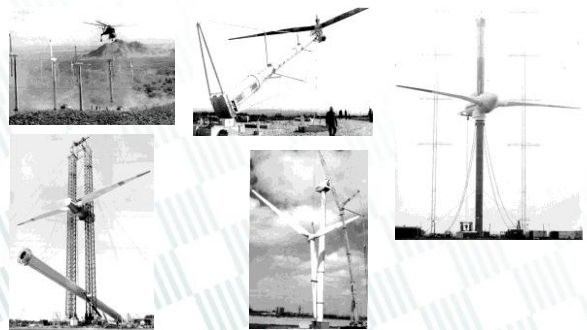
### Upscaling



## Structural aspects

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### Installation methods



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## Offshore applications

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### Offshore Potential

- Garrad-Hassan/Germanische Lloyd: In Europe-12 x the total present electricity consumption in coastal areas
- Greenpeace/DEWI: 3 x electricity consumption
- Different national studies underway (F, GB, D) or finalized (NL, DK, S)

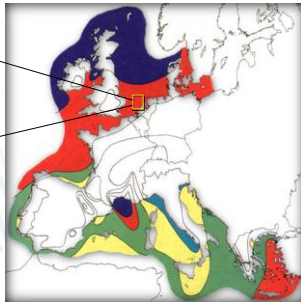
## Offshore applications

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### Potential in The Netherlands



Area 45 km x 45 km is sufficient to supply 100% of current average electricity consumption in NL



## Offshore applications

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### Limitations on land

#### Shortage of good sites:

- Denmark, Northern Germany

#### Institutional limitations (lack of public acceptance?):

- Netherlands

#### Environmental limits:

- GB, Sweden

#### RE non issue:

- Belgium, France



## Offshore applications

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### Offshore Wind Energy; a special case?

North Sea, Baltic Sea, Irish Sea

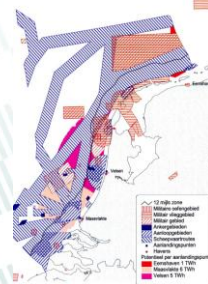
- Shallow
- Windy
- Near
- Surrounded by countries with high energy use (Germany, UK, Netherlands, Belgium, Denmark, Sweden, Finland)

## Offshore applications

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### Offshore Potential; restrictions

Example the Netherlands



- Water depth
- Distance from shore
- Shipping
- Military
- Dredging
- Cabling
- Fishing
- Oil and gas mining
- Pipelines

ECN (vd Noord)

## Offshore applications

### Offshore Categories

The diagram illustrates the progression of offshore wind farm categories over time. It shows four stages: onshore (1990), shallow water (2000), near shore, and far offshore (2020). Each stage is represented by a photograph of wind turbines. A blue arrow at the bottom indicates the timeline from 1990 to 2020. A large blue arrow points from the onshore category towards the far offshore category.

onshore 1990 shallow water 2000 near shore far offshore 2020

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## Offshore applications

### From modified land concepts to dedicated offshore installations ?

Two photographs of offshore wind farms. The left image shows the ENRON Tacke wind farm with several turbines in the sea. The right image shows the Lagerwey the Windmaster (NL) wind farm, featuring a large, white, lattice-structured tower.

ENRON Tacke Lagerwey the Windmaster (NL)

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## Offshore applications

### Foundations

Three photographs showing different types of offshore wind turbine foundations. The first image shows the Bonus (DK-NL) foundation, a large concrete structure. The second image shows the NedWind (NL) foundation, a red and white structure. The third image shows another Bonus (DK) foundation, a large concrete structure.

Bonus (DK-NL) NedWind (NL) Bonus (DK)

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## Offshore applications

### Existing offshore windfarm projects (2009)

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Horns Rev II	209	Denmark	91 x Siemens SWP 2.3-93	2009
Lynn and Inner Dowsing	194	United Kingdom	54 x Siemens 3.6-107	2008
Nysted Wind Farm	166	Denmark	72 x Siemens 2.3	2003
Horns Rev	160	Denmark	80 x Vestas V80-2MW	2002
Princess Amalia	120	Netherlands	60 x Vestas V80-2MW	2008
Lillgrund	110	Sweden	48 x Siemens 2.3	2007
Egmond aan Zee	108	Netherlands	36 x Vestas V90-3MW	2006
Rhyl Flats	90	United Kingdom	25 x Siemens 3.6-107	2009
Burbo Bank	90	United Kingdom	25 x Siemens 3.6-107	2007
Barrow Offshore Wind	90	United Kingdom	30 x Vestas V90-3MW	2006
Kentish Flats	90	United Kingdom	30 x Vestas V90-3MW	2005
Scroby Sands	60	United Kingdom	30 x Vestas V80-2MW	2004
North Hoyle	60	United Kingdom	30 x Vestas V80-2MW	2003
Middelgrunden	40	Denmark	20 x Bonus 2MW	2001

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## Offshore applications

### Offshore windfarm projects in construction (2009)

Wind farm	Capacity (MW)	Country	Turbines and model	Completion
Greater Gabbard wind farm	500	United Kingdom	140 x Siemens 3.6-107	2011
BARD Offshore 1	400	Germany	80	2010
Sheringham Shoal Offshore Wind Farm	315	United Kingdom	88 x Siemens 3.6-107	2010
Thanet Offshore Wind Project	300	United Kingdom	100 x Vestas V90-3MW	2011
Radsand II	200	Denmark	72 x Siemens 2.3-93	2010
Robin Pigg (Solway Firth)	180	United Kingdom	60 x Vestas V90-3MW	2009
Gunfleet Sands Offshore Wind Farm	172	United Kingdom	48 x Siemens 3.6-107	2010
Bligh Bank	165	Belgium	55 x Vestas V90-3MW	2011
Ormonde Wind Farm	150	United Kingdom	30 x RePower 5M	2010
Donghai Bridge Wind Farm	100	China	34 x Sinovel 3 MW	2010
Tricase	90	Italy	38 x 2.4 MW	2012
Alpha ventus	60	Germany	6 x REpower 5M, 6 x Multibrid M5000	2009
Gasslingegrund	30	Sweden		2009

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## Offshore applications

### Planned offshore windfarm projects

Wind Farm	Capacity (MW)	Country
Dogger Bank	9,000	United Kingdom
Norfolk Bank	7,200	United Kingdom
Wasatch Wind	4,400	Canada & USA
Inish Sea	4,200	United Kingdom
Hornsea	4,000	United Kingdom
Firth of Forth	3,500	United Kingdom
Great Lakes Array	1,600	Canada
Atlantic Array	1,500	United Kingdom
Bristol Channel	1,500	United Kingdom
Moray Firth	1,300	United Kingdom
Triton Knoll Wind Farm	1,200	United Kingdom
Codling Wind Park	1,100	Ireland
London Array	1,000	United Kingdom

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## Environment - planning

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### What are the issues?

- Birds
- Noise
- Landscape
- Shadow and light reflection
- EMC
- Degree of acceptance
- CO2 reduction

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## Environment - planning

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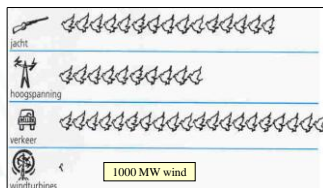
### Birth deaths



Birdwatch by radar in the Netherlands



Birdwatch Tune Knob (DK)



1 bird symbol: 100.000 bird deaths.

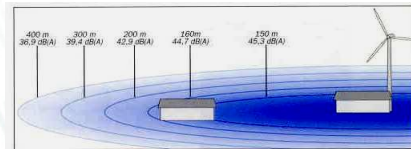
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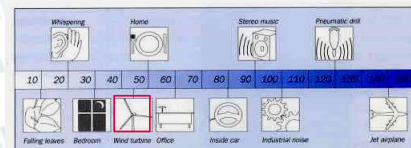
## Environment - planning

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### Noise emission



#### Relative noise levels



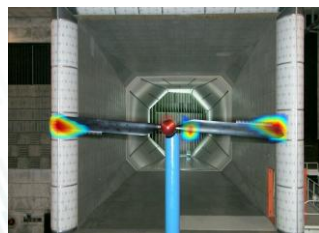
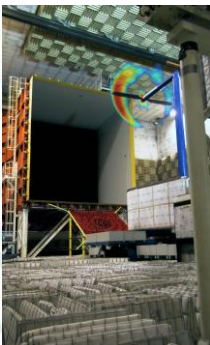
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## Environment - planning

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### Noise emission research



DNW, ECN, Uni Stuttgart

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## Environment - planning

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### Wind park configuration; line positioning



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## Environment - planning

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### Visual effects versus size

8 x 28m (0,25 MW)

2 x 53m (1 MW)

1 x 75m (2 MW)

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## Environment - planning

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### Multi functional use

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## Market and economy

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#	Nation	2005	2006	2007	2008	2009
-	European Union	40,722	48,122	56,614	65,255	74,767
1	United States	9,149	11,603	16,819	25,170	35,159
2	Germany	18,428	20,622	22,247	23,903	25,777
3	China	1,266	2,599	5,912	12,210	25,104
4	Spain	10,028	11,630	15,145	16,740	19,149
5	India	4,430	6,270	7,850	9,587	10,925
6	Italy	1,718	2,123	2,726	3,537	4,850
7	France	779	1,589	2,477	3,426	4,410
8	United Kingdom	1,353	1,963	2,389	3,288	4,070
9	Portugal	1,022	1,716	2,130	2,862	3,535
10	Denmark	3,132	3,140	3,129	3,164	3,465
11	Canada	683	1,460	1,846	2,369	3,319
12	Netherlands	1,236	1,571	1,759	2,237	2,229
13	Japan	1,040	1,309	1,528	1,880	2,056
14	Australia	579	817	817	1,494	1,712
15	Sweden	509	571	831	1,067	1,560
<b>World total (MW)</b>		<b>58,924</b>	<b>74,151</b>	<b>93,927</b>	<b>121,188</b>	<b>157,899</b>

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## Market and economy

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### Market development in the past

Source: BTM Consult ApS - March 2001

BTM

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## Market and economy

ETC

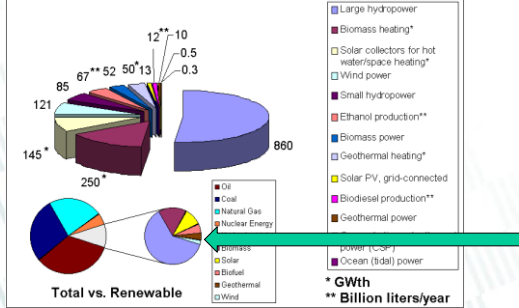
### Market development in the future (2)

CASINDO Training Course on Renewable Energy Part II – MEMR

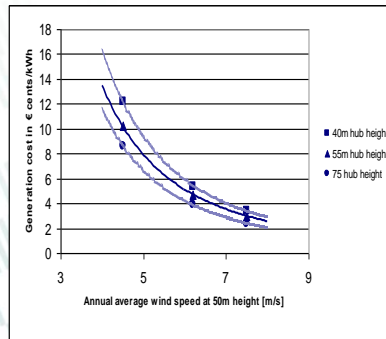
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Wind energy in perspective

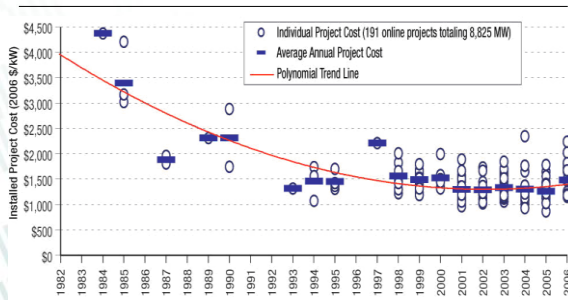
Renewable energy, end of 2008 (GW)



Costs development versus time and size



Installed project cost versus time



Source: Berkeley Lab database (some data points suppressed to protect confidentiality).



Thank you for your attention!

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