Cost and Potential of Offshore Wind Energy on the Dutch part of the North Sea

H.J.T. Kooijman[1], M. de Noord[1], C.H. Volkers[1],
L.A.H. Machielse[1], F. Hagg[2], P.J. Eecen[1], J.T.G. Pierik[1] and S.A. Herman[1]
[1] ECN, Energy research Centre of the Netherlands, P.O. Box 1, 1755 ZG, Petten, The Netherlands,
tel. +31 224 56 4115, fax. +31 224 56 8214, e-mail kooijman@ecn.nl
[2] Stork Product Engineering, Amsterdam, the Netherlands f.hagg@ecn.nl

ABSTRACT: With the growing attention for offshore wind energy seen today there is a need for a sophisticated, quantitative investigation of the opportunities for offshore wind energy. The Energy research Centre of the Netherlands (ECN) has therefore developed a computer program named OWECOP. The program couples a Geographic Information System (GIS database) with an Excel spreadsheet program.
The GIS database contains relevant properties of the water area like ambient wind speed, dimensioning wave height, water depth, and distance to shore. The Excel spreadsheet program includes different engineering models to calculate the cost of the turbine, for the support structure, electrical infrastructure, transport, installation and operation and maintenance. The gross energy yield and overall efficiency of the farm are also calculated with Excel. After user defined choices have been made for the type of turbine, the farm lay out and the economic parameters, the cost and potential of wind energy in the water area can be calculated in Excel, based on the site-specific information in the GIS database. The transfer of information from the GIS database to the Excel calculation models goes automatically. Investigations have been done for the Netherlands Exclusive Economic Zone (EEZ) in the North Sea. It takes several hours to complete one run.
The OWECOP cost models are currently further improved in order to deal with some recognised deficiencies and will be finished by the end of 2001. Analysis for other European waters is envisaged.

Keywords: Resources, Cost Analyses, Cost of Energy, Off-Shore.

1 INTRODUCTION

With promising locations for wind turbines on land running scarce and the road to building permits in Western-Europe often long and windy, there is a growing interest among policy makers, project developers, industry, and research institutes for offshore wind energy over the last few years.

Offshore wind energy is however still more expensive than onshore wind energy, despite the higher wind resource at sea. To make sure that the offshore wind farm will be cost effective, relying on the economies of scale, it needs to consist of at least some tens of large wind turbines. To limit the risk of the high investment costs involved, it is worthwhile to identify the most promising sites at forehand and to compare them on a qualitative basis. In that way the lowest cost price can be achieved. This is not just because the energy output would simply be the highest but also because of the fact that due to the higher confidence the amount of private capital and the costs for insurances can be reduced and hence the effective interest rate would be low.

This paper introduces a computer program that enables a comprehensive analysis of offshore wind energy. The program is applicable to any site if relevant data is available. At the end results are presented of the first investigations that have been done for the Dutch Exclusive Economic Zone (EEZ).

The program is named OWECOP, which stands for Offshore Wind Energy – Cost and Potential. It was (and is further) developed by the units Policy Studies and Wind Energy of the Energy research Centre of the Netherlands in co-operation with Stork Product Engineering in Amsterdam. It is due to be completed by the end of the year 2001. OWECOP aims to inform both policy makers and project developers.

2 THE OWECOP PROGRAM

OWECOP consists of two programs that are coupled: a Geographic Information System (GIS database) with maps containing information on the waters investigated and an Excel spreadsheet program. The GIS database contains – for example per 10*10 km sized grid cell - information on:

- ambient wind speed;
- water depth;
- 50 year return period significant wave height;
- distance to a harbour and distance to a location for grid connection.

The Excel spreadsheet program has different modules to calculate on an engineering basis the following costs of the different building blocks:

- turbine;
- support structure;
- electrical infrastructure;
- transport;
- installation;
- operation and maintenance;
- decommissioning;
- gross energy yield;
- factor between gross and net energy yield, i.e. turbine and farm availability, losses due to wake effects in the farm and losses due to power transport.

In addition the following parameters need to be filled in by the user before doing the OWECOP analysis:

- wind turbine type in terms of installed power, specific rotor area and variable or fixed rotor speed;
- farm lay out, i.e. the total number of turbines and the split up in turbines per group and per line, the spacing between rows of turbines, between the turbines in a row and, if desired, also the distance between groups of turbines in the farm;
- economic properties of the wind farm, i.e. the division of the capital investment in private money, loans and equity, and their corresponding interest rates. Together with the economic lifetime this defines the effective interest rate for the project.

If all input parameters have been defined in Excel the potential wind energy yield and cost price of the energy can be calculated per grid cell. For the definition of cost price see e.g. ref. [12].

The exchange of information from GIS to Excel and vice versa goes automatically. A complete run for the analysis of the Netherlands Exclusive Economic Zone (EEZ) in the North Sea takes some several hours to complete.

2.1 GIS database

The Geographic Information System is an existing program that is widely used for cartographic work. For the purpose of investigating the cost and potential of offshore wind energy, it serves as a database for mapping information on ambient wind speed, water depth, 50 year return period wave height, distance to a harbour and distance to a location for grid connection.

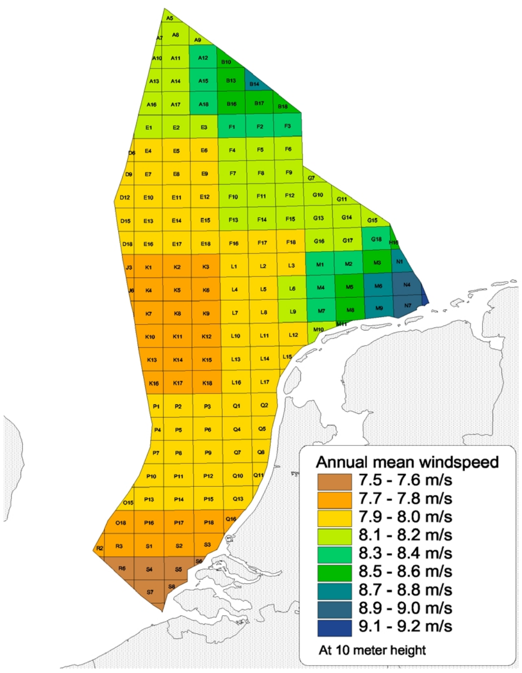

Figure 1: Ambient wind speed at 10 m height at the Dutch EEZ, based on information from ref. [1], [2], [4], [6] and [7].

The default resolution is 10*10 km, which is in fact a trade off between the level of resolution of the results and the calculation time.

For the first investigations a database has been used of the Dutch part of the North Sea which already contained valuable up to date information on areas that are reserved for shipping routes, military zones, fishery, etc.

More information can easily be added to the database if this would be considered relevant for the calculation models in the Excel workbook. Figure 1 shows the wind resource for the Dutch EEZ defined by ECN Wind Energy.

2.2 Excel spreadsheet program

The calculations are performed in Excel to determine the cost and potential energy yield per grid cell based on the information received from the GIS database. Parameters need to be filled in for the type of turbine and farm lay out and values have to be defined for the economic parameters in order to determine the interest rate for the wind farm.

The cost models are empirically defined or - in case of the support structure - based on first order engineering rules for the required strength. Important information has been obtained from earlier studies, see e.g. ref. [9] and [10]. An overview of the different cost calculations is given below.

- Turbine costs are calculated with an existing empirical cost model set up by Stork Product Engineering; ref. [5]. Important parameters are the amount of installed power, specific rotor area, fixed or variable rotor speed and the nominal value. Figure 2 gives an example cost breakdown of an offshore wind turbine.

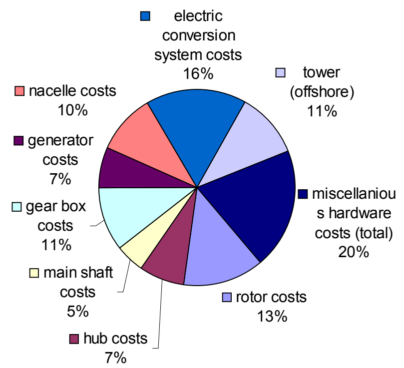

Figure 2: Cost breakdown for 2.5 MW variable speed offshore turbine.

- Electrical infrastructure costs are determined using an engineering model. The program chooses between a HVAC and a HVDC power connection to the shore depending on the kWh price of the net energy. The outcome depends on the difference in investment costs for power conversion and the cable losses per kilometre for each of the two options.
- Support structure costs (tower and foundation) are based on an engineering approach for the required structural strength of the construction and specified prices per kilogram steel per construction part. In

combination with geometrical boundary constraints for transport and installation the program seeks for the cheapest feasible option between a monopile and a tripod foundation. A more elaborate description of the model is given in ref. [5]. Figure 3 shows an example.

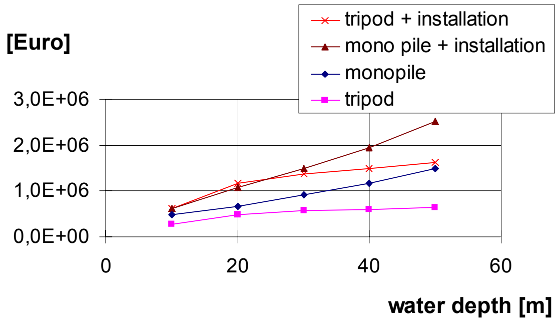

Figure 3: Trade off between a tripod and a monopile foundation for a 2.5 MW turbine in 20 m deep water exposed to a 50 year significant wave height of 12 m.

- Transport and installation costs are calculated based on the size and weight of the entire structure, the installation strategy and possibilities and limitations of the installation vessel. The model is currently being verified and adapted to information gained from the industry.
- Operation and maintenance costs can either be calculated as a linear function of the distance to the nearest harbour or specified in more detail using the prescribed annual operation costs and (anticipated) return period and costs per component for retrofits.

An example cost breakdown of an offshore wind farm is shown in Figure 4.

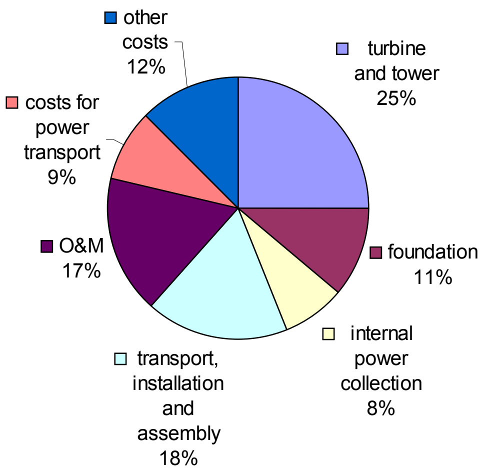

Figure 4: example cost breakdown from the OWECOP model for a 50 * 2.5 MW OWE farm in the North Sea at 25 km from the coast.

The difference between the calculated gross energy yield and net energy depends on the following 5 aspects:

1. Turbine availability (depending on the distance of the farm to a harbour and the type of turbine concept chosen, i.e. robustness of the design);
2. Park availability (limited availability due to e.g. cable damage or ship collision);
3. Electrical losses for the collection and conversion of power in the farm;
4. Power losses for the transport of electricity to the shore;
5. Aerodynamic losses due to wake effects in the farm, depending on on the one hand the wind rose (ref. [11]) and on the other hand the size of the farm, the spacing between the turbines and whether the turbines have constant or variable rotor speed.

The calculation of the energy yield on basis of the above data and the ambient Weibull parameters and shear data is straightforward.

3 RESULTS FOR THE NETHERLANDS EEZ

A first investigation has been done for the Netherlands Exclusive Economic zone at the North Sea. Some assumptions are:

- a spacing of 6 diameters between the turbines and 9 diameters between lines of turbines;
- an annuity of 10.0%;
- commercial market prices as estimated to be realistic in 3 years time, ref. [8].

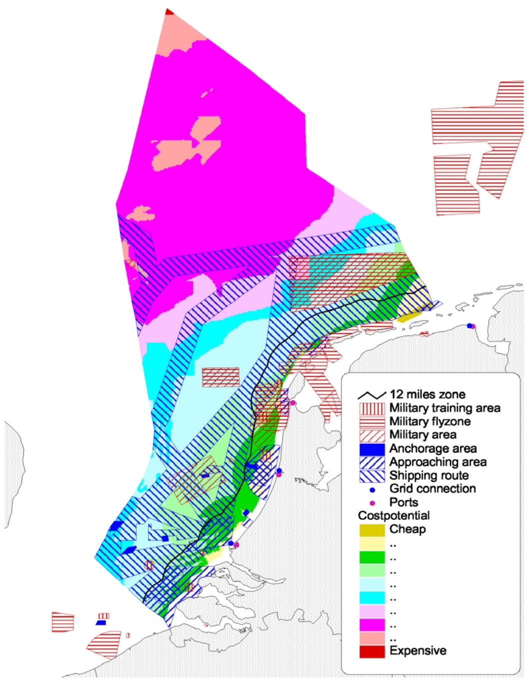

Figure 5: Cost analysis for the Dutch EEZ. Hatched areas indicate exclusions because of shipping routes, etc.

It was seen that for the 56 thousand square kilometres on the Dutch EEZ more than 30 thousand are potentially available for the offshore wind energy. This would theoretically suffice for 4 to 5 times the national electricity use of the Netherlands, ref. [3]. 10 % of the electricity consumption can potentially be generated with OWE at a cost price of 10 euro cents or less.

4 CONCLUSIONS

A computer program has been developed to determine the cost and potential of offshore wind energy, coupling a GIS database with simplified calculation models for costs and net energy yield.
A first analysis has been done for the Dutch part of the North Sea. The final model will be ready by the end of 2001. Analysis of other European waters is envisaged.

Acknowledgement

The work presented in this paper is funded by the ENGINE programme of ECN to support future energy solutions.

REFERENCES

[1] Cleijne, J.W., A.J.M. van Wijk en A.M. Holtslag; *Comparing wind speeds on the North Sea coast and offshore*. E-connection (no complete reference available).

[2] Cleijne, J.W., J.P. Coelingh en A.J.M. van Wijk; *Description of the North Sea Wind climate for offshore wind energy applications*. TNO Environmental and Energy Research, Apeldoorn, the Netherlands, November 1991.

[3] Corten, G.P.; *Share of Wind Energy, version November 11, 2000*. ECN Wind Energy, internal note.

[4] Deutsche Wetterdienst; *Climate of the North Sea. Einzelveröffentlichungen Nr. 118* Hamburg. Offenbach am Main 1998.

[5] Hagg, F.; *Kostenmodel Offshore Windenergie voor beleidsstudies*. ECN Wind Energy internal note, Petten, 16 November 2000.

[6] J.P. Coelingh (editor*); Long term wind speed climate & Temporary characterisation of wind and wave coupling*. DOWEC concept study Tasks 5 and 6. ECOFYS, February 2000.

[7] Korevaar, C.G.*; North Sea climate - based on observations from ships and lightvessels*. KNMI. Kluwer publishing, Dordrecht, 1990.

[8] Machielse, L.A.H.; *Vergelijk praktijkgegevens met resultaten van het model voor "Kosten en opbrengst van windenergie op het Nederlandse Continentale Plat"*. ECN-Wind Memo 01-001, Petten, January 2001.

[9] Novem; *Plaatsingsplan windenergie buitengaats* (diverse rapporten). Novem, Utrecht, May 1999.

[10] Stork Engineering Consultancy et al.; *Near shore wind energy - Technische realisatie* (several reports). In commission from Novem, SEC B.V., 30 September 1997.

[11] Wieringa, J. *Wind structure and wind climate.* Appendix to chapter 7 of the module "Windenergie conversiesystemen 1 (b29)", Delft University of Technology, Delft, February 1991.

[12] Zaaijer, M.B. et al.; *Starting-point and Methodology of Cost Optimisation for the Conceptual Design of DOWEC - final draft*. DOWEC concept study Task 9, Delft, 23 March 2000.