HOW TO BENEFIT FROM COST MODELLING OF OFFSHORE WIND FARMS?

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Summary
Cost models for offshore wind farms have been developed and applied in various projects, with different purposes. This paper presents considerations and guidelines obtained from the experiences with the application of cost models. Some of the pitfalls of the development of models for this multi-disciplinary application are identified of which the risk of inconsistency is a prominent one. One of the leading considerations for the applicability of a cost model is its accuracy. Depending on the objective of the project, different types of inaccuracies are either acceptable or frustrating the distinctive abilities of the model. The level of complexity of a universal, flexible and accurate cost model will generally convince developers into the implementation of a simplified model, which has to match the users objective.

Keywords: Wind farms, Offshore, Cost modelling, Economics

Introduction

Ever since the idea of offshore wind energy took form, people have been occupied with cost modelling of offshore wind farms. After all, the only way to obtain insight in the economic viability of the non-existing concept is to estimate the costs and energy yield by designing the wind farm to significant detail. As knowledge advanced and implementation of large offshore wind farms became more realistic, cost modelling became more precise and the focus of application shifted from feasibility assessment to optimisation. Currently, the following objectives can be identified for cost models: policy support, siting, feasibility, concept selection, parameter optimisation and budget assessment. Several questions have risen from the experience with these models: How to deal with the multi-disciplinary nature of offshore wind energy? How does the application of the model relate to its functional requirements? Are the results accurate enough for the particular research question? etc. This paper provides considerations to answer these questions, based on the experience of the authors with cost models for the projects Opti-OWECS [1], DOWEC [2], [3], [4], Probabilistic Decision Analysis (PDA) [5], OWECOP [6], [7], [8] and literature [9], [10], [11]. The cost model of the Opti-OWECS project relies to a large extent on engineering models and expert user input. The primary targets of this model were feasibility assessment and concept selection. A derivate of this model was used in a GIS package as a policy and siting tool [12]. The core of the OWECOP model consists of curve fits to results from more specified studies and programs and engineering models, verified with market information and catalogue data as far as available. This model is also implemented in a GIS package for policy and siting applications. The cost model used for DOWEC is mainly based on curve fits to engineering models and design work performed by the project team. This model is used in a concept study of offshore wind farms, in which the optimisation of the wind farm for a specific site is analysed. The PDA tool has been developed in parallel with modelling of DOWEC costs. Financing and bookkeeping issues that come into the picture at a later stage, when the outline of a project is more or less defined, are not addressed here.

Economic assessment

The economics of offshore wind farms are based on two aspects: the costs of generating electricity and the market value of electricity from (offshore) wind energy. The first aspect, costs, is largely a technical issue relating to the design and performance of the wind farm and the costs of financing. The second aspect, value of wind energy, is largely a social issue relating to energy policy and the value of other sources of energy. Evidently, this distinction is slightly exaggerated as for instance performance in terms of predictability, variability and controllability can have significant effect on the value of energy. Besides, there are coupling effects between the two aspects, such as stimulating (tax) measures that tend to bridge the gap between costs and benefits and the increase of prices from suppliers in a market with good income perspectives. In the longer term a good value of wind energy can bring down costs by increasing the volume, as particularly the German and Danish markets have proven. However, for the purpose of this paper the costs of generation and the value of wind energy will be considered as two inputs that can be determined separately.

A large variety of assessment parameters and methods has been developed for economic analysis [13], [14]. Three of the more commonly used parameters will be discussed here: Net Present Value, Internal Rate of Return and Levelised Production Costs. The Net Present Value (NPV) is the present value of an investment's future net cash flows including the initial investment. If positive, the present value of the incomes exceeds the present value of costs, including an assumed discount rate. The NPV is a good indicator of the absolute present value of the profit of a project over the entire economic lifetime, after subtraction of the financing costs at the assumed discount rate. The Internal Rate of Return (IRR) by definition is the rate of return or discount rate at which the Net Present Value of a stream of payments/incomes is equal to zero. The IRR is a good indicator of the relative return on an investment, but the duration of the debt terms depend on the timing of the payments and incomes. The Levelised Production Costs

(LPC) equal the present value of all costs divided by the discounted value of the electricity production. The LPC is a valuable indicator of the average cost of energy in terms of current purchasing power. In calculating these parameters the economic lifetime should equal the technical lifetime of the wind farm, unless the present value of the depreciated wind farm at the end of the economic lifetime is included as income.

The main difference between NPV and IRR on the one hand and LPC on the other is that the first two incorporate knowledge of both costs and benefits, whereas the last one only deals with costs (LPC is expressed as costs per unit energy yield). The direct relation between NPV and IRR makes them two forms of the same principle looked at from a different angle. Many other economic parameters that look at the problem from a slightly different perspective follow the same principles and are either associated with a cost/benefit assessment or a cost-only assessment.

Types of applications
The following objectives can be identified for cost models for offshore wind farms: policy support, siting, feasibility, concept selection, parameter optimisation and budget assessment. The first question that rises is: is a costs-only assessment suitable, or is a costs/benefit analysis required? Since the LPC provides a minimum price that should be paid to cover the investment and discount, it is a convenient parameter for comparative studies of technologies, independent of possibly temporary, local or dedicated tariff systems. As utilities and energy policy-makers are interested in the costs of energy of different technologies and developers and designers want to compare different sites, concepts or designs for offshore wind turbines and farms, the IEA (International Energy Agency) has recommended the use of the LPC as a primary assessment criterion [15].

A straightforward comparison of the LPC for different technologies implicitly assumes that the 'inherent' value of electricity is the same for all technologies: if a kWh of electricity obtained from wind energy costs less than a kWh obtained from a conventional power plant, the first is (economically) preferred. However, this approach neglects two aspects. First, the value of electricity depends on its quality, particularly in a liberalised electricity market. As stated before, properties such as predictability and power quality present an inherent value, which will result in a persistent higher market value. In the DOWEC project several concepts for offshore wind turbines and farms are compared on an LPC basis. This approach complicated the quantification of the benefits of good power quality (next to the fact that the economic benefits of good power quality in future are unclear at the moment). Second, increased value of environmentally friendly electricity at least partly represents an inherent property of this type of electricity. Although some of the increased value may be due to stimulating policy, part is related to the avoided costs of environmental pollution. It is reasonable to consider this part as a long-lasting and global increase of the market value of sustainable technologies. Both issues should be considered in the economic assessments of utilities and policy-makers, whereas the first issue (the value of good quality) is relevant for a comparison of different concepts for the conversion of offshore wind energy. Only if the value of electricity is nearly the same for all compared configurations, such as in an optimisation study, a costs-only assessment is appropriate. The inclusion of benefits, as in the assessment of NPV and IRR, is evidently required for feasibility and budget studies by investors or when comparing different options for energy generation.

A cost model for a multi-disciplinary application
Cost models are built with a variety of approaches. On one side of the spectrum the entire design process is captured in an engineering model. At the other side of the spectrum all costs and energy yield are based on quotations from manufactures, contractors or a design team. The design model is most powerful and can provide information for a wide variety of inputs, but it is also very complex. The quotation approach shifts the complexity to the design team, making it less flexible but usually more precise. Prudency is required to distinguish between off-factory quotations and market prices. The adopted approach should also be reported when issuing calculated LPC values. The advantage of quotations is that much information is readily available, although a match or extrapolation with the intended application is necessary. Hybrid versions also exist, in which the essentials of designing offshore wind farms is translated to more or less parameterised functions.

To model the costs of an offshore wind farm, in some way the wind farm itself must be modelled. Eventually all kinds of modelling approaches (quotations, curve fits, scaling rules, engineering models, guestimates, expert input) originate from a design process. The interactions between the various aspects of the offshore wind farm require an interaction between the design teams of the various involved disciplines. Therefore, the development of a cost model requires the same interaction and cannot be a simple accumulation of models from the separate disciplines. The developers of cost models have to be aware of the large risk of inconsistency, when these interactions are neglected. The user of the cost model is likely to be a layman in at least a few of the involved disciplines. When input or interaction variables get out of the range of validity of one of the sub-models, the user will not always be able to detect this from the output, particularly when the output is merely a cost or efficiency figure. Furthermore, the sub-models have to be generated for the same configuration. For instance, the costs of a support structure for a stall-regulated turbine can differ from those for a pitch-regulated turbine. Last but not least, the breakdown of the model has to be consistent and complete. Although this is an obvious statement, significant factors are sometimes overlooked and by unclear definitions for instance cable-laying costs could be doubled in electrical infrastructure costs and installation costs. An early version of the DOWEC cost model added the costs of scour protection to the costs of a support structure for which scour protection was not required. Administration and checks of validity are essential tools to guarantee consistency within the multi-disciplinary model. Also, the model should be well-balanced. Accuracy and likewise the effort to model different aspects should be in proportion to the impact each aspect has on the eventual result.

Accuracy

The accuracy that is required from a cost model depends on the type of application as indicated in table 1. In some cases the absolute accuracy is important, but in comparative studies a systematic offset can usually be allowed, provided that differences are correctly calculated. The magnitude of the absolute or relative accuracy also depends on the type of application and on the phase of the project. In general, the closer to the final definition or design the higher the required accuracy.

Table 1 Importance of type of accuracy for difference applications of a cost model.

	Absolute accuracy	Relative accuracy		
		Site variation	Design parameter variation	Design concept variation
Policy making	+	+		
Siting support		++		
Feasibility	+			
Budget assessment	++			
Design parameter optimisation			++	
Design concept selection				++

As mentioned before, cost models can be built from different types of building blocks, such as quotations, curve fits, scaling rules, engineering models, guestimates and expert input. With respect to accuracy a cost model differs from physical models in two essential ways: it models a design process, in which physical models are part of a design loop, and it models economics, in terms of cost estimations. The following (incomplete) list of error sources can be identified:

- General sources of error
  - Inaccuracy in input parameters
  - Human errors (modelling, implementation and input)
  - Simplification of interactions between sub-models
- Physical models
  - Imprecise knowledge of the physical process
  - Simplification of the physical model
- Design process
  - Propagation of errors from physical models
  - Negligence of design drivers
  - Simplification of requirements and constraints
  - Sub-optimum design solutions
  - Unknown (future) technologies and materials
- Economic model
  - Insufficient specification of design and procedures
  - Simplification of material and labour costs
  - Simplification or negligence of certain external conditions (availability of equipment, personnel and working space)
  - Negligence of strategic considerations and human interaction (negotiations)

Ironically, all error sources accumulate to potentially large errors in the costs per component, but once this is turned into a binding quotation from a manufacturer or contractor it obtains absolute validity. In practice, this will not happen for applications other than the budget assessment for an actual implementation project. Particularly for offshore construction, maintenance and shipyard activities the costs tend to be very dependent of non-technical factors that cannot be modelled accurately. In parameter optimisation studies this influences the direction of optimisation only slightly, since the largest part of the associated error is correlated. However, when different concepts are compared, e.g. a monopile and a tripod, the errors in manufacturing costs are highly uncorrelated and may form an uncertainty that exceeds the difference in costs.

The accuracy of a cost model can be determined from two angles: an internal or an external assessment. In an internal assessment the accuracy is estimated from an analysis of the building blocks and the propagation of errors to the accuracy of the outcome. In an external assessment the cost model is considered as a black box, and the accuracy is estimated from analysis of the outcome. The first approach is difficult because of the complexity of the building blocks and their interactions. The second is complicated by the lack of reference data. A sensitivity study can help to determine which inputs and building blocks are most significant contributors to variations in the outcome. Often, the development and application of cost models in projects focus on the results and the evaluation of accuracy is fairly limited.

Probabilistic approach
One way to deal with uncertainties in the model outcome is to apply a probabilistic approach. By variation of input parameters the cumulative probability density function of the outcome is determined. A probabilistic approach is used for instance in Probabilistic Decision Analysis (PDA), in which the probability of an economic advantage is estimated for an investment, when compared with a reference (e.g. a different investment or no investment). By its nature, PDA is suitable for a feasibility study or for support of an investment decision for a well-defined project. In siting and design studies the method is less suitable, due to the large development and computation effort. Design of an offshore wind farm is a multi-parameter and multi-concept optimisation and in a probabilistic approach each individual comparison step in the optimisation loop is associated with the calculation of a cumulative density function, requiring large computation time and many parameter dependencies in the model. The advantage of probabilistic information in this process is doubtful, given the expectation that the outcome with 50% probability of exceedence will be near the outcome of estimated median values for the inputs. During the design process a probabilistic analysis is suitable to obtain insight in the uncertainty in the prediction, due to the stochastic nature of some of the inputs. However, there are a few pitfalls. First, although obvious, non-stochastic input data (such as rotor diameter) must not be treated as such. Second, there may be a misinterpretation of the required statistics of the input. For instance, a user may input a high and low expected value of the yearly failure rate of one turbine, while a high and low value of the average for all wind turbines over the entire lifetime is required. The latter values are separated far less than the ones per turbine. Third, PDA generally assumes uncorrelated inputs. Even though models with correlated inputs can be implemented, there is a risk of using the wrong correlation. For instance, in a siting study wind climate is more or less uncorrelated for widely separated sites, but in a concept study wind climate should be the same for both concepts. This last pitfall also demonstrates that the implementation of the correlation of the stochastic inputs depends on the type of application of the model.

So, how can we benefit from cost modelling?
First of all, there is no such thing as ‘the one cost model for offshore wind energy’. When using or (re-) developing a cost model for offshore wind energy, one has to be aware that the cost model must match the target of the application, particularly with respect to accuracy and the type of features one wants to distinguish. The last issue also relates to the selection of independent parameters. With the current widespread and competitive status of wind energy, the required higher accuracy may demand modelling of the value of electricity in some cases, in order to quantify the quality of the energy conversion.

In decreasing order, cost modelling of offshore wind farms is suitable and required for the following applications. At the same time, these applications are in increasing order with respect to suitability of using quotations for cost and energy yield from a design process of an engineering team.

- feasibility for various dimensions and sites (simple models provide sufficient accuracy)
- assessment of distribution of costs and cost drivers (simple models provide sufficient accuracy)
- parameter optimisation (correlated errors drop out of comparisons)
- siting (correlated errors drop out of comparisons)
- concept selection (concept specific models required and uncorrelated errors do not drop out)
- budget assessment (high accuracy but low flexibility required)

Due to the complicated and multi-disciplinary character of offshore wind energy, cost models need to be used in accordance with their specific goal and are only valuable when the origin of the cost and energy functions are well documented. First, this enables a consistency check for different contributions and, second, it enables the user to track the underlying design solution for a particular outcome. Last, but not least, the user of the cost model cannot be considered an expert in all fields of offshore wind energy and the documentation is needed by others to verify the conditions in which a cost or energy function is applied.

References

[1] Cockerill, T.T., et. al., Development of a Cost Model for Offshore Wind Energy, Opti-OWECS Final Report Vol. 2: Methods Assisting the Design of Offshore Wind Energy Conversion Systems, Part A, Institute for Wind Energy, Delft, 1998.
[2] Herman, S.A., DOWEC Cost Model – Implementation. DOWEC-F1W2-SH-01-068/01-C. ECN report number ECN-CX-02-048. Petten, April 2003.
[3] Herman, S.A., Kooijman, H.J.T., DOWEC concept variation study, DOWEC-F1W2-SH-03-087/00-C, Draft, ECN, Petten, May, 2002.
[4] Zaaijer, M.B., e.a., Overall cost-modelling of the DOWEC lifecycle in a wind farm, DOWEC-F1W1-MZ-01-037/01-P, 19 September, 2001.
[5] Wels, H.C., A decision analysis model for offshore wind turbines, NRG, Arnhem, December 2001.

[6] Herman, S.A., Offshore Wind Farms. Analysis of Transport and Installation Costs. ECN-I-02-002. Energy research Centre of the Netherlands, Petten, February 2002.
[7] Herman, S.A., Probabilistic Cost Model for Analysis of Offshore Wind Energy Costs and potential. ECN-I-02-007. Energy research Centre of the Netherlands, Petten, May 2002.
[8] Kooijman, H.J.T. et al, Cost and Potential of Offshore Wind Energy on the Dutch Part of the North Sea, paper presented at the EWEA Special Topic Conference on Offshore Wind Energy, Brussels, 10-12 December 2001. Energy research Centre of the Netherlands, document number ECN-RX-01-063. Petten, September 2001.
[9] Danish Wind Turbine Manufacturers Association, Guided tour on wind energy, Internet: http://www.windpower.org, accessed April 2003.
[10] Diveux, T., Sebastian, P., Bernard, D., Puiggali, J.R., Grandidier, J.Y., Horizontal Axis Wind Turbine Systems: Optimization Using Genetic Algorithms, In: Wind Energy, Vol 4, pp. 151-171, John Wiley & Sons Ltd., 2001.
[11] Fuglsang, P., et. al., Site-specific design optimization of wind turbines, In: Wind Energy, Vol 5, pp. 261-279, John Wiley & Sons Ltd., 2002.
[12] Cockerill, T.T.; Harrison, R.; Kühn, M.; Bussel, G.J.W. van, Opti-OWECS Final Report Vol. 3: Comparison of Cost of Offshore Wind Energy at European Sites, Institute for Wind Energy, Delft, 1998.
[13] Manwell, J.F., McGowan, J.G., Rogers, A.L., Wind energy explained, Chapter 9, University of Massachussetts, Amherst USA, John Wiley & Sons Ltd., September 2002.
[14] Investorwords.com, Financial glossary, Internet: http://www.inverstorwords.com, accessed April 2003.
[15] Nitteberg, J. (editor); Boer, A.A. de; Simpson P.B., Expert Group Study on Recommended Practises for Wind Turbine Testing and Evaluation, 2. Estimation of Cost of Energy from Wind Energy Conversion Systems, IEA, 1983.