Vessel fleet optimization for maintenance operations at offshore wind farms under uncertainty

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Abstract

We study the problem of determining the optimal fleet size and mix of vessels to support maintenance activities at offshore wind farms. A two-stage stochastic programming model is proposed where uncertainty in demand and weather conditions are taken into account. The model aims to consider the whole life span of an offshore wind farm, and should at the same time remain solvable for realistically sized problem instances. The results from a computational study based on realistic data is provided.

Problem description

Today, the offshore wind energy industry needs financial support to be profitable, and producers in the United Kingdom receive a subsidy of approximately EUR 100 per MWh produced . Following the initial investment, the largest cost component is the cost of operations and maintenance (O&M) activities, which may constitute between 20--25 % of the life-cycle costs of an offshore wind turbine. The cost of vessels, helicopters and infrastructure used to support O&M activities is one of the largest cost elements during the operational phase of an offshore wind farm. With a many different vessels available, all with their strengths and weaknesses, the question then becomes which vessel fleet is the most cost effective for any given offshore wind farm(s)?

In addition, we also consider different base options, such as a normal onshore base, mother vessel concepts, artificial islands and offshore platforms. While offshore base concepts probably are too expensive for small wind farms, they may be useful if they are able to serve several wind farms in close proximity to each other.

Mathematical model

The problem is formulated as a two-stage stochastic mathematical model. The key elements of this model are:

- the goal is to minimize total costs
- more than one wind farm may be considered
- the wind farm(s) are built in several steps, spanning several years
- the vessels may be purchased and sold at different points in time
- there is uncertainty in the amount of maintenance to perform
- there is uncertainty in the time available for maintenance work
- uncertainty is captured through scenarios in a two-stage model

The first stage decisions are:

- Which vessels to buy, sell, charter in, and charter out each year
- Which base(s) to use

The second stage decisions for a given scenario with a given weather and failure realization ensure that all maintenance tasks are performed with the fleet decided in stage one, and calculates the estimated downtime costs.

Results

When testing the model we have considered one or several offshore wind farm(s) located in the North Sea. Initial testing showed that it was sufficient to use 50 scenarios to achieve good in-sample stability, while out-of-sample stability required fewer scenarios. The computational experiments show that the mathematical model provide close to optimal fleet size and mix decisions within short CPU times. The model provides significant added value compared with the deterministic counterpart in some instances. Closer inspection reveals that much of the Value of stochastic solution comes from the costly investments in a jack-up rig. The stochastic model is more reluctant to purchase such a rig, preferring to charter in whenever needed for small wind farms. The deterministic expected value problem is eager to invest in a rig, not being able to see that the special demand for the rig will be irregularly distributed.

Furthermore, the computational study showed that for some instances it is valuable to take uncertainty in demand and weather conditions into account. However, it is surprising that the value decreases for larger wind farms, and it is possible that for this particular problem a more detailed representation of the tactical planning is needed. However, the model will quickly become impractical to solve, and this appears to be a challenging prospect for future research.

Conclusions

- Model is most valuable for relatively small wind farms
- Stability tests show that at least 50 scenarios is needed to get stable results that are independent of the scenario tree
- Computing times are low (as long as 1% cut off)

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