PO.271

# Automated Optimisation Method for Wind Farm Noise

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## Introduction

Wind farm noise assessments require a careful balance to be struck between:

- Using the full available generating potential of a site and
- controlling the risks of excess noise generation.

As developable land suitable for wind farms becomes less and less available, more challenging sites are having to be selected. At the same time, improvements in turbine technology have meant that a variety of noise-controlled modes are available for modern variable speed machines. This allows noise reductions to be applied, in the required conditions, at a marginal but sometimes appreciable energy cost. It is also possible to adapt the mitigation strategies according to different wind directions, by accounting for the reduced noise propagation found in upwind conditions.

Typically, the operational strategy for a wind farm would be developed iteratively by an engineer, using a heuristic approach, until compliance was achieved.

But there are some issues with this approach:

- there can be different strategies that result in compliance;

*Which is better: fewer turbines operating without any constraint or a greater number in reduced noise modes?*

- If the focus is on noise compliance, the associated power production is not always considered.
- Each receptor is considered in turn, as it is too difficult to manually consider an optimal result which accounts for all locations at the same time.

## Approach

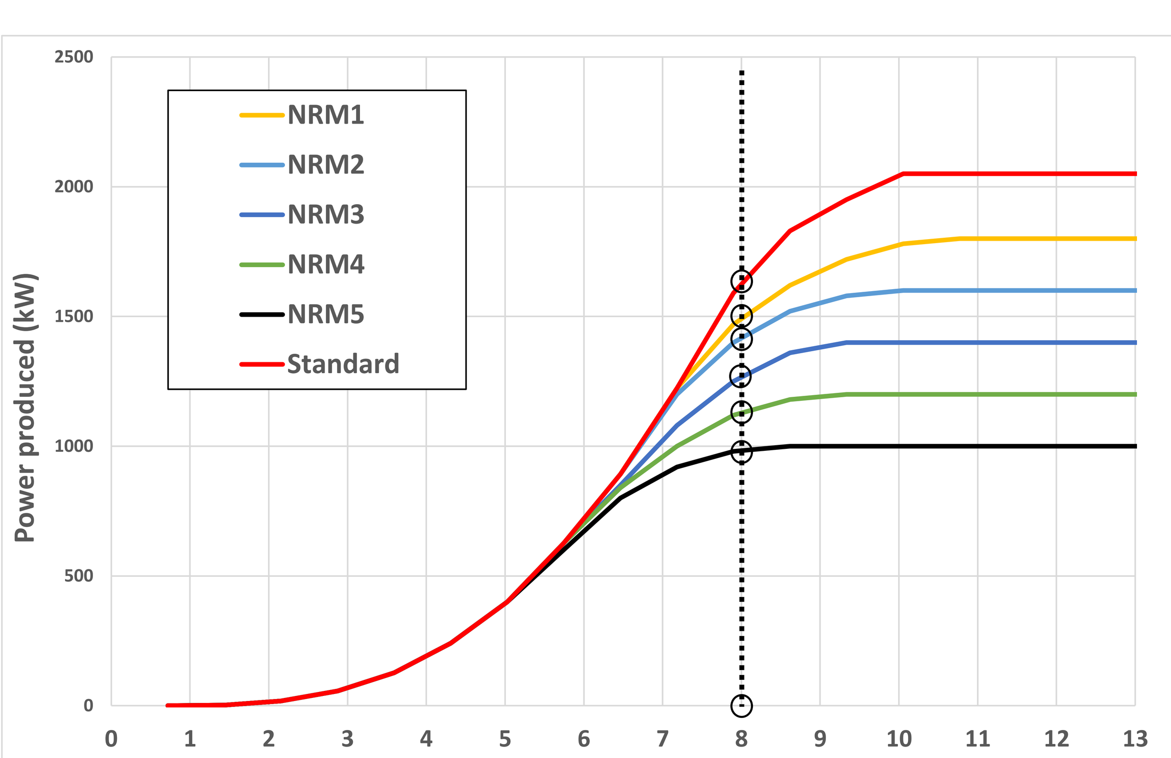


**Figure 1: power curves for different Noise Reduced Modes (NRM), showing changes in power production for a certain wind speed.** For example, mode NRM5 produces 5 decibel (dB) less noise at a key wind speed but at a cost of 40% of power generation.

The authors have developed a new approach to this challenge, by first considering not just the noise but also the associated energy generation for each turbine.

Manufacturers provide the noise emissions of their turbines in different Noise Reduced Modes (NRM), but also different power curves for each of the NRMs. At a fixed wind speed, the power production of each mode can be directly compared: see Figure 1.

For a given wind speed and direction, we can therefore calculate the energy cost of each noise compliance strategy, and therefore compare these to determine the compliant choice which is optimal in terms of energy. This can support the heuristic approach described above by providing a performance metric for each strategy.

## Optimisation method

The complexity of the problem rapidly increases with the number of turbines, as the number of possible combinations increases exponentially:

*On a 17 turbine site, with each turbine potentially operating in 7 different operating modes (or turned off), this represents more than 2 $10^{15}$ possibilities.*

But finding the combination of operating modes with the best overall power production represents a discrete optimization problem, bound by the requirement to comply with the noise limits. To solve this problem in an optimal way, rather than consider all possible solutions, an algorithm using the "branch and bound" [1] approach was developed by the authors.

Using a predictive model, the contribution of each turbine to the noise levels at each property is first calculated, resulting in a contribution matrix. Each combination of modes then results in a calculated noise level at all properties using this matrix. The optimisation approach is then illustrated in Figure 2.

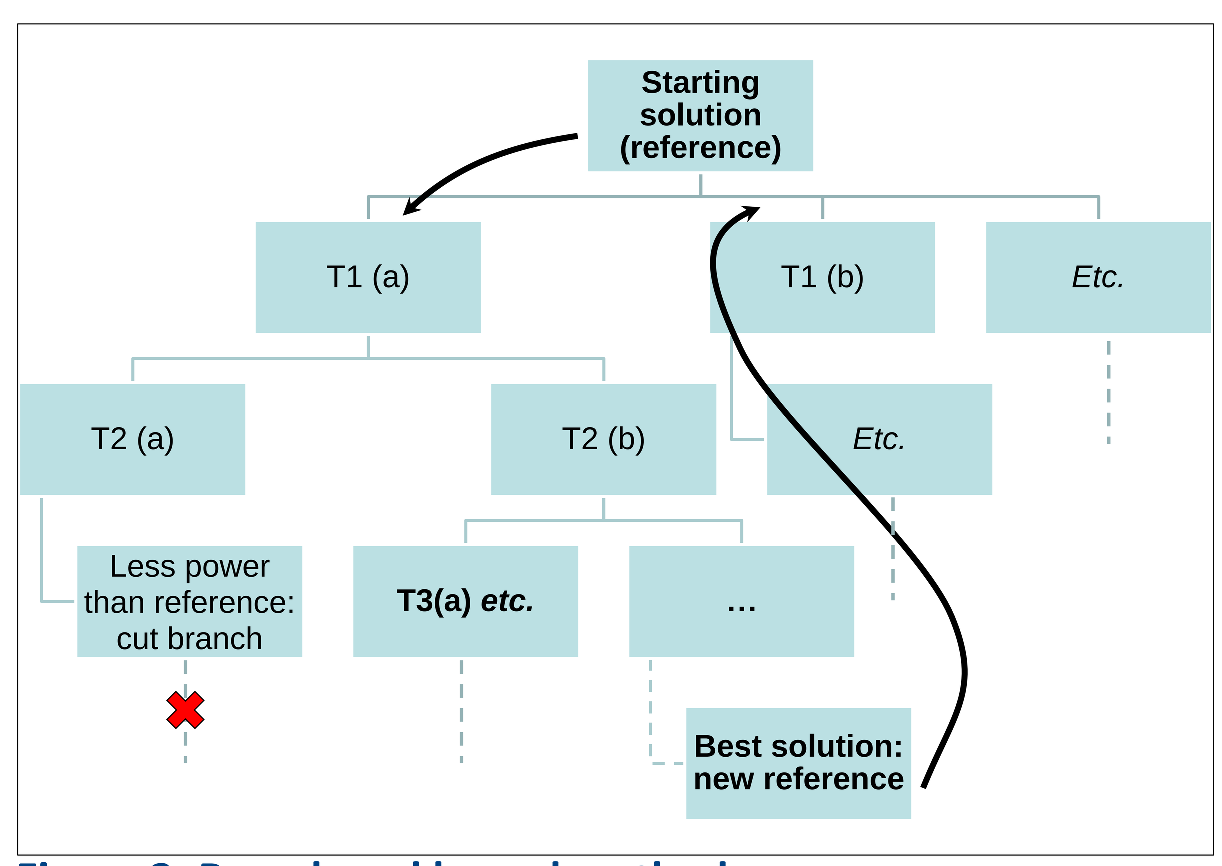


**Figure 2: Branch and bound method**

Starting with a reference working solution, with a certain power production, the algorithm explores a "tree" of possible alternatives for each turbine in turn, checking in each case that the predictions still meet the noise limits at each surrounding location. The tree of possible options is explored recursively, but restricting the exploration to branches which can give a better power production than the reference, and "cutting" branches which are less optimal: this new optimal solution becomes a new reference, and a new branch is explored until an optimum is determined.

## Initial results

The algorithm developed was first applied to a simple three-turbine site. Compared to a "brute force" method which considers all possible scenarios, the optimisation method reduced the calculations required by **80 to 90%**.

The calculated solution was not dependent on the starting assumption, which provides further assurance that an optimal strategy was obtained. Even with such a simple layout, the calculated solutions resulted **in 1 to 3% more power production** than for a manually calculated solution. This was most likely because the optimisation software considers all neighbouring properties at the same time rather than each in turn.

## Example application

Fig. 3a shows a more complex example with a fictitious 17-turbine layout. The objective was to comply with a noise level of 40dB(A) at a single property (L) at a key wind speed, using different approaches.

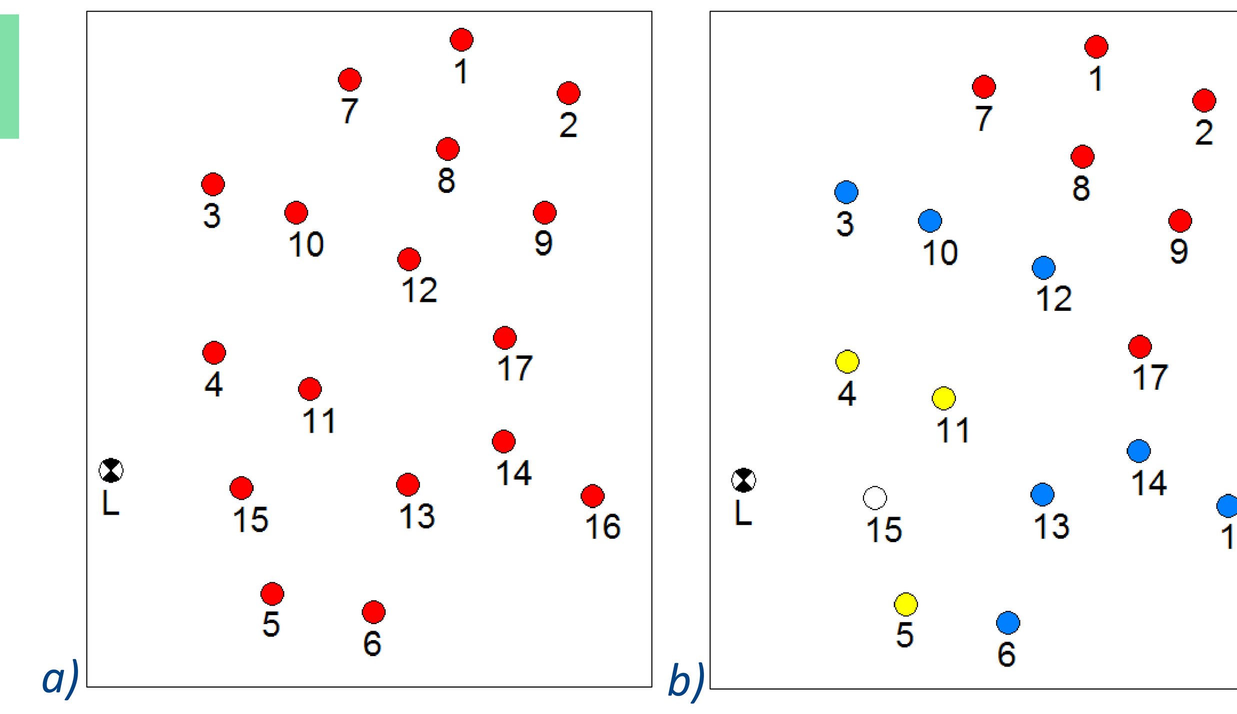


**Figure 3: Example of a fictitious 17 turbine site: a) initial layout, b) optimal operational modes**

The analysis was first done on a "manual" basis using two different approaches:

- All turbines operating in a single NRM**:** the resulting power production was **29MW**.
- *But with the nearest turbine switched off (or removed), this allows 15 of the other turbines to operate in a less restrictive noise mode, with a total power generation of **32MW, a gain of 10%**. This is counter-intuitive and illustrates the difficulties with this analysis.*

The automatic optimisation method described above was then applied. With 17 turbines, the number of operations required to determine a solution using the branch and bound algorithm is of **8 orders of magnitude** less than if all possible combinations were evaluated (which would be practically impossible to calculate in this case). The result was a more complex mixed operation strategy, with three different noise modes, as illustrated in Fig. 3b.

- This resulted in an increased power production of **34MW**, a **further gain of 4%, or 15%** compared to the first approach. This objectively shows that removing turbine 15 was the optimal approach.

## Uncertainties and future work

The method developed considers each wind speed and wind direction in isolation. Further analysis is required to develop an overall control strategy, on a case-by-case basis depending on the limitations of each turbine model's control systems.

The analysis currently assumes a uniform wind speed across the site. A knowledge of the site-specific wind speed distribution would allow refining the optimisation.

Predictive noise models are subject to some uncertainty. But the model used, based on ISO 9613-2, has been subject to extensive validation on actual wind farms [2].

## Conclusions

A novel automated turbine mode optimisation method has been developed, to jointly consider noise constraints as well as the associated power production of different strategies. An efficient automated algorithm was developed to determine an optimal configurations, even on large wind farm projects. This has been applied at a number of sites by the authors. Avenues for further development were identified. This method could also be of use for turbine manufacturers to develop different noise-reduced modes on a site-specific and optimal basis.

## References

1. Jens Clausen, University of Copenhagen, Branch and Bound Algorithms - Principles and Examples (March 1999).
2. Wind Farm Noise Predictions and Comparison with Measurements, A. Bullmore, J. Adcock, M. Jiggins, M. Cand. Proc. Wind Turbine Noise 2009 Conference, Aalborg Denmark, (June 2009)