

# Wind Farm Layout Optimization Case Studies 3 & 4

IEA Task 37 on System Engineering in Wind Energy

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## 1 Introduction

Two major factors that affect wind farm layout optimization are 1) the optimization approach and 2) the wake model. We have thus far conducted two case studies to analyze differences in these variables, this document defines a third and fourth case study to further study these factors when given more realistic wind farm boundaries. Case study 3 presents a scenario with a concave boundary. Case study 4 presents a scenario with both concave boundaries and discontinuous boundary regions. For case studies 3 and 4, the user is free to choose both optimization approach and wake model.

Participants will (1) optimize turbine locations to maximize annual energy production, (2) submit solutions with details regarding their optimization convergence and methodology. After all submissions are received, participants will be expected to perform a cross comparison of other participant solutions. Data will be consolidated, processed, and made available to all participants.

## 2 Problem Definition

### Objective

The objective of each scenario is to maximize annual energy production, which we define simply as the expected value of aerodynamic power. For case studies 3 and 4, the wind resource is supplied in 120 bins. Each bin has a directional probability and associated wind speed distribution with Weibull parameters. Participants are free to use all, fewer, or interpolate more  $n$  directional bins for their optimizations if they wish. In other words:

$$AEP = 8760 \frac{\text{hrs}}{\text{yr}} \sum_{i=1}^n \sum_{j=1}^m f_i w_j P_{i,j}$$

where  $P_{i,j}$  is the power produced for wind direction  $i$  at wind speed  $j$ ,  $f_i$  is the corresponding wind direction probability, and  $w_j$  is the windspeed sampled from the given continuous Weibull distribution.

### Design Variables

The design variables are the  $(x, y)$  locations of each turbine, all hub heights ( $z$  values) will be the same in these case studies. Every turbine in the farm is identical, and defined below in **Parameters**.

### Constraints

In case studies 1 and 2, all farm boundaries were uniformly circular and centered on the origin. To make these studies more realistic, the boundaries are non-uniform, and case study 4 is made up of discontinuous regions. It is based on the Borselle III and IV wind farms, and our version is depicted graphically in Figure 1. The coordinates for the boundary vertices are given in `iea37-cs3-boundary.yaml` and `iea37-cs4-boundary.yaml`. All turbine rotor radii must remain completely on or within this boundary. No turbine hub can be less than two rotor diameters from any other hub.

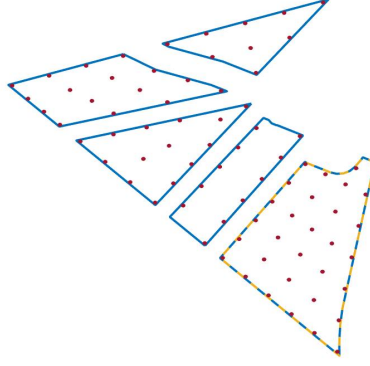


Figure 1: Graphic depiction of wind farm boundary for case study 3 (outlined in yellow) and case study 4 (outlined in blue). An example layout of turbines for case study 4 are placed in red.

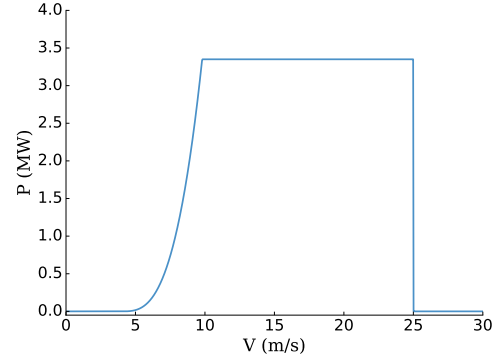
## Parameters

The wind turbine is the IEA37 10 MW offshore reference turbine [1] with the following characteristics:

Rotor Diameter	198.0	m
Turbine Rating	10	MW
Cut-In Wind Speed	4	m/s
Rated Wind Speed	11	m/s
Cut-Out Wind Speed	25	m/s

All turbine data is also contained in the enclosed `iea37-10mw.yaml`. The power curve is defined as:

$$P(V) = \begin{cases} 0 & V < V_{cut-in} \\ P_{rated} \cdot \left( \frac{V - V_{cut-in}}{V_{rated} - V_{cut-in}} \right)^3 & V_{cut-in} \leq V < V_{rated} \\ P_{rated} & V_{rated} \leq V < V_{cut-out} \\ 0 & V \geq V_{cut-out} \end{cases}$$



The farm wind speed for both scenarios is given in Weibull parameters for each bin. The +y axis is coincident with  $0^\circ$ , and the CW wind rose is defined by 120 discrete bins tabulated in `iea37-cs3-windrose.yaml`, depicted pictorially below:

## 2.1 Baseline Layouts

Since both the files supplied to users necessary for participation, as well as the resulting output provided by each participant are in very precise formats, baseline layouts for both case studies are supplied. These files are called `iea37-cs3-baseline.yaml` and `iea37-cs4-baseline.yaml`. Like the example layouts provided for case studies 1 and 2, this baseline layouts are meant to provide a reasonable minimum output against

which results can be measured. Participants are not required to use the baseline layouts as starting points for their optimizations, though they are permitted to do so.

Users participating in case studies 3 and 4 will use their own wake model (thus the specific model-computed AEP values in the `.yaml` files will vary), but the baseline layouts are supplied as example submissions, to understand the specific `.yaml` reporting format we require.

## 2.2 Case Study 3

This problem defines a scenario where the user is free to choose both the optimization algorithm and the wake model. This single wind farm scenario is twenty-five (25) turbines with a boundary containing concavities. The boundary is depicted graphically outlined in yellow in Figure 1 and vertices are explicitly defined in `iea37-cs3-boundary.yaml`.

## 2.3 Case Study 4

This problem adds discontinuous boundary regions to the problem presented in case study 3. The user is free to choose both the optimization algorithm and wake model. It is requested that participants use the same algorithm and model that they used in case study 3 in order for us to observe scalability differences, but users are not required to do so. This single wind farm scenario is eighty-one (81) turbines with a boundary containing concavities and discontinuities. The boundaries for case study 4 are graphically depicted in Figure 1 outlined in blue, and vertices are explicitly defined in `iea37-cs4-boundary.yaml`.

# 3 Reporting and Evaluation

Participants will submit:

1. Optimal turbine placement solution using the `.yaml` format from the enclosed baseline layout.
2. Optimization performance and timing metrics using the `.yaml` format from the enclosed baseline layouts.

Note that your `.yaml` submissions must report both total farm AEP, and farm AEP for each of you chosen binned wind directions, as in the enclosed `iea37-cs#-baseline.yaml` examples.

## 3.1 Reporting

Since results will be analyzed mainly through cross-comparison, submissions must adhere to the `.yaml` format in order to receive a ranking. Submitted files should be named:

`$iea37-cs#-yourname.yaml`

Where:

- “`cs#`” is the case study number of the submission (“`cs3`” or “`cs4`”).
- “`yourname`” is your personal or organizational name, all lowercase with no spaces or punctuation.

The following two files must be referenced internally by your submission, as is done by the baseline layout:

- `iea37-cs3-windrose.yaml` describes the Weibel distribution wind rose used in both case studies.
- `iea37-10mw.yaml` lists the turbine data for the used IEA37 10 MW offshore reference turbine.
- `iea37-cs#-boundary.yaml` which gives the point outline of the wind farm boundaries.

As shown in the example results given in `iea37-cs#-baseline.yaml` files, (1) number of function calls, (2) intermittent AEP calculations, (3) and turbine locations at each iteration will be required. This means each participant must log the intermittent AEP calculations and number of function calls at **each** iteration through the optimization process, to track data regarding time to convergence. This data will be submitted in your single submission file. An example of the format is included in `iea37-cs#-baseline.yaml`.

## 3.2 Evaluation

Because the participant wake models are intended to differ, determining a “best” solution is generally not possible. Comparisons will be made using a cross-comparison approach, as was done in case study 2. Every participant will evaluate every other participant’s solutions using their own wake model(s). It is essential that the `.yaml` format is adhered to so that cross-comparisons are painless.

## 4 Enclosures

Files included with this document, needed for full participation in the case studies are:

- `iea37-cs3-windrose.yaml` - the same for both `cs3` and `cs4`, binned in 120 directions with continuous Weibull distributions for windspeed in `.yaml` format
- `iea37-10mw.yaml` - data for reference turbine used in both case studies, in `.yaml` format
- `iea37-cs3-boundary.yaml` - the coordinates of the wind farm’s boundary for case study 3
- `iea37-cs4-boundary.yaml` - the coordinates of the wind farm’s boundary for case study 4
- `iea37-cs3-baseline.yaml` - example optimization results, denoting timing and iteration analysis
- `iea37-cs4-baseline.yaml` - example optimization results, denoting timing and iteration analysis

## References

- [1] Bortolotti, P., Dykes, K., Merz, K., Sethuraman, L., and Zahle, F., “IEA Wind Task 37 on System Engineering in Wind Energy, WP2 - Reference Wind Turbines,” Tech. rep., National Renewable Energy Laboratory (NREL), Golden, CO., May 2018.