uc3m | Universidad **Carlos III** de Madrid

Master in Statistics for Data Science
2024-2025

Master Thesis

"Optimizing Wind Turbine Placement in Wind Parks via Mixed Integer Optimization using Neural Network based Constraint Learning."

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Madrid the 29. of January

Acknowledgments

TODO Acknowledgments

ABSTRACT

This thesis combines Linear Optimization with Constraint Learning to optimize wind turbine placement for maximum performance in a predefined area under randomly distributed wind. A Neural Network is trained on simulated data to model the impact of turbine positioning on power output. This model is integrated as a constraint in a linear optimization problem, and the problem evaluated for a current state-of-the-art wind farm configuration.

CONTENTS

1 INTRODUCTION

With the clean energy transition currently taking place in europe with ambitious targets for 2030 and beyond [4] , wind energy is playing a central role in that transition, with wind energy expected rise to 50 % in the EU energy mix. [3] With wind energy thus expected to become the main contributer to the EU's energy production and large potentials identified for both onshore and offshore parks [1] attempts to optimize all parameters of windparks with even minor power efficeny improvement can be expected to yield significant returns in absolute power due to the scale of future wind energy production.

As a contribution to increasing power efficeny on future wind farms, this thesis is dedicated to a new approach for optimizing the placement of a fixed number of wind turbines in a predefined area (typically a square). To solve this optimization problem, a extension to the pyomo python library is used, that allows the introduction of Neural Networks to the optimization problem as constraints. [2] This extension allows for introducing a Neural Neural Network to model the effects of wind turbine placement relative to each other on power production for the respective windturbines. Introducing this model to the optimization problem defined in pyomo then allows for the optimization of overall power productions across all wind turbines in the wind park. The optimization problem in its simplest form can be defined as

$$\max_{\mathbf{x},\mathbf{y}} \sum_{i=1}^{n} f_{Power,\mathrm{NN}}(x_i, y_i; \mathbf{x}, \mathbf{y}) \tag{1}$$

$$\text{s.t.} \quad X_{\min} \le x_i \le X_{\max}, \quad \forall i \in \{1, \dots, n\} \tag{2}$$

$$Y_{\min} \le y_i \le Y_{\max}, \quad \forall i \in \{1, \dots, n\} \tag{3}$$

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \ge d_{\min}, \quad \forall i \ne j \tag{4}$$

where:

- (x_i, y_i) are the coordinates of turbine i out of n total turbines,
- $f_{\mathrm{NN}}(x_i, y_i; \mathbf{x}, \mathbf{y})$ is a neural network approximating the power output for each turbine i ,
- $X_{\min}, X_{\max}, Y_{\min}, Y_{\max}$ define the boundaries of the rectangular placement
- $d_{\min}$ is the minimum distance between any two turbines.

To create a model optimally fit to the needs of the optimization problem, the model is trained on data specifically generated with the FLORIS wind farm simulation tool for optimal coverage of the parameter space of the optimization.

To simplify the problem, the surface below the turbines is assumed to be perfectly flat and equal wind speed is assumed along the entire hight of the turbines.

Data Generation and Neural Network:

(...)

Optimization Problem:

(...)

This thesis is structued according to the two main steps required to solve the optimization problem as presented above.

2

STATE OF THE ART

3 FARM POWER MODEL

With the goal of training a model tailor made to the requirements of the optimization problem, the data used for training the model has to generated using a open source simulation method, allowing to set the parameter space of the model as required to the given optimization problem. After investigating the two python based wind farm simulation tools FLORIS and PyWake, FLORIS was chosen due to solid documentation, what appears to be very stable releases and broad functionalities regarding wake modelling. FLORIS is a wind farm simulation tool developed by the National Renewable Energy Laboratory (NREL).

Wind turbine power curve modelling under wake conditions using measurements from a spinner-mounted lidar: https://www.sciencedirect.com/science/article/pii/S

Floris: https://github.com/nrel/floris

Main Effects of Wake Turbolence: - Wind Speed (needs time to mix with outside airflow) - Turbolence

3.1 DATA SOURCE

3.2 MODELLING

3.3 VALIDATION

4 OPTIMIZATION

5

ADDENDA

6 ABBREVIATIONS

ACM	Aerodynamic Characteristics Model

LIST OF FIGURES

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BIBLIOGRAPHY

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