Cartography M.Sc.

ITC

Faculty of Geo-Information Science and Earth Observation

Spatial Optimization for Wind Farm Allocation

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Presentation outline

1. Introduction
2. Research problem
3. Research goal
4. Methodology
5. Analysis and results
6. Discussion
7. Conclusion and outlook

Introduction

- Importance of renewable energy
- EU strategy for sustainable future
- Wind energy as a serious competitor
- 11% of EU energy demand
- **€43bn** investment in 2016

http://www.cityenergy.org.uk/wp-content/uploads/2015/03/renewable-energy.jpg

Introduction

Wind Farm Development

Choosing suitable locations for wind farms is a complex and time-consuming process influenced by a number of factors:

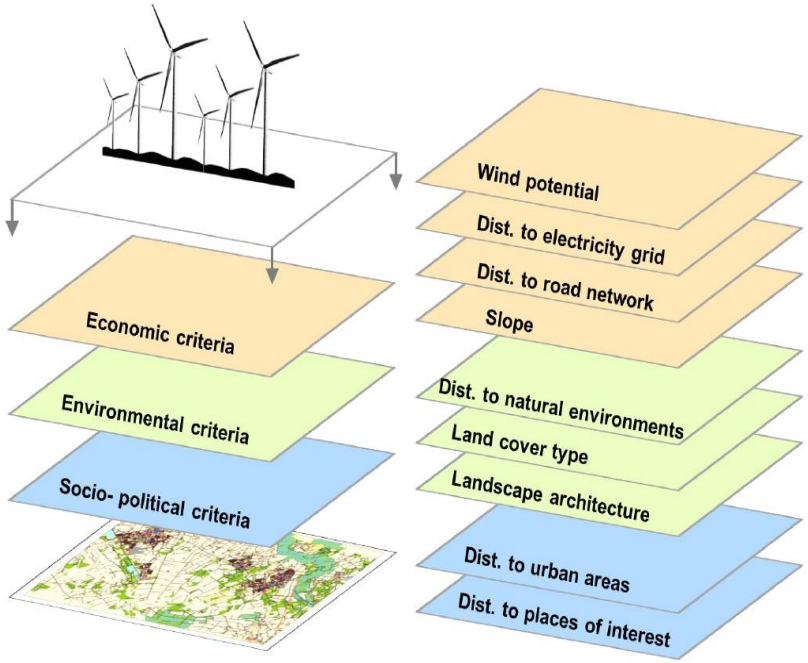
- Wind energy potential
- Distance from roads
- Distance from electricity grid
- Distance from urban areas
- Distance to natural reserves
- Land use and land cover
- Slope of terrain
- Social acceptance

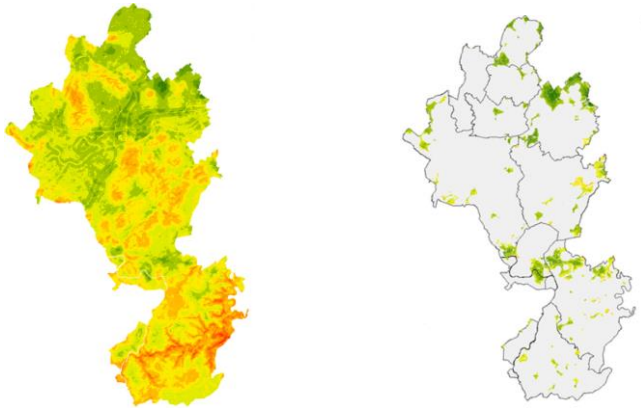
(NIMBY syndrome, visual intrusion, noise annoyance, shadow flickering effect, negative effects on birds and bats)

Research problem

GIS-MCDA

- Available land estimation
- Suitability analysis
- Wind Farm Layout Optimization (WFLO)
- Exploitation of more land requires advances in the current assessment techniques





Sunak et al.,(2015) 'A GIS-based Decision Support System for the Optimal Siting of Wind Farm Projects'

Research goal

Develop an optimization method to facilitate the search for optimal allocation scheme for wind farms

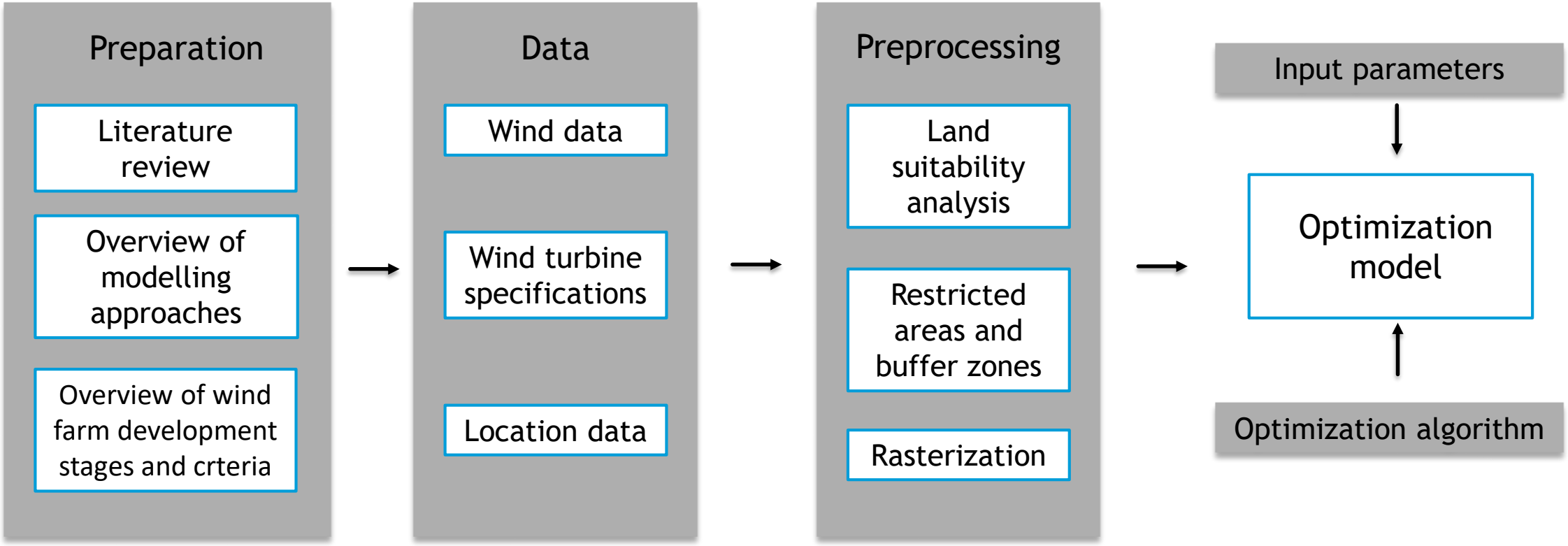
1. Identify the main factors that influence wind farm development
2. Develop an understanding of the spatial optimization methods and their main aspects
3. Define the mathematical problem of placing wind turbines in a region of interest
4. Create a model that will determine the maximum energy production of an area depending on the size and number of the wind turbines

Research goal

Research questions

1. How to formulate an objective function in order to maximize the AEP (Annual Energy Production)?
2. Which multi-objective optimization techniques are best for a wind farm layout scenario?
3. Should this model account for turbine wakes, and how can this effect be incorporated into the model?
4. Which optimization algorithm will provide the best trade-off between accuracy of the output result and computing effort?
5. How to assess the quality of the model?

Methodology



Methodology

1. Data Preparation

I. Turbine specifications

	D (Rotor diameter)	H (Hub height)	Vi (Cut-in speed)	Vo (Cut-out speed)	Vr (Rated speed)	Pwr (Rated power)
ENERCON ENERGY FOR THE WORLD	53 m	60 m	4 m/s	22.50 m/s	12 m/s	800 kW
Vestas	90 m	95 m	4 m/s	25.00 m/s	12 m/s	2000 kW
SIEMENS	142 m	129 m	4 m/s	25.00 m/s	11 m/s	3150 kW

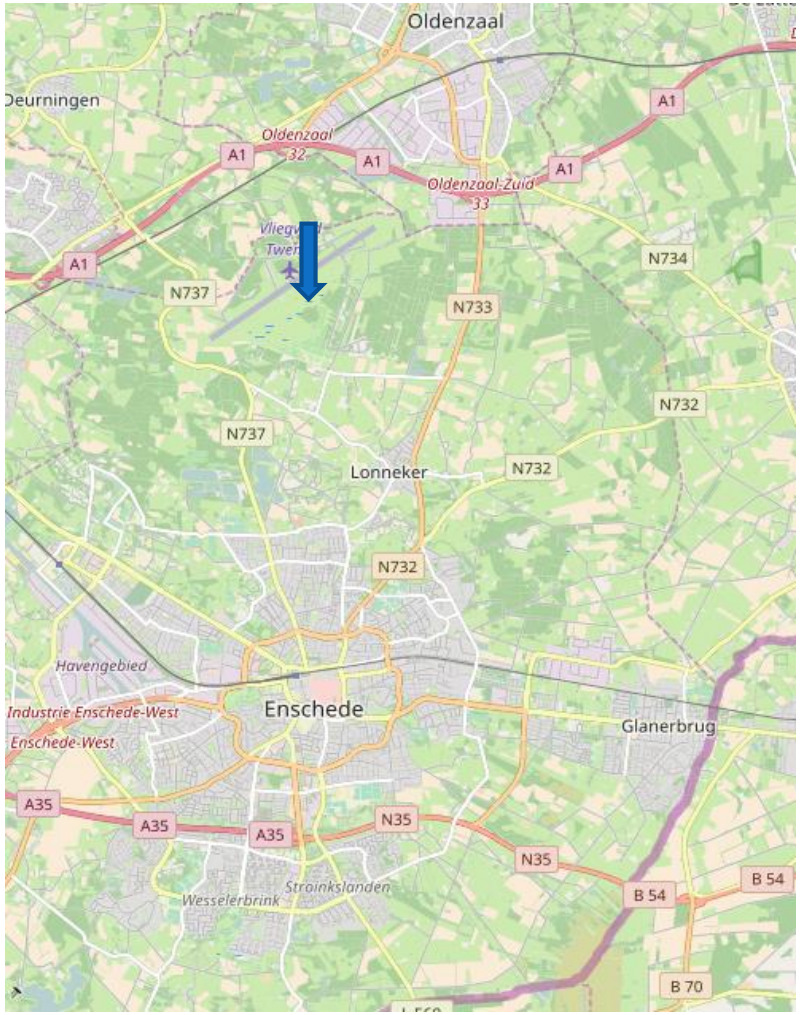
Methodology

1. Data Preparation

II. Wind data

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Measuring Station No	Measuring Station Name	LON (east)	LAT (north)	ALT (m)
290	TWENTHE	6.891	52.274	34.80



Methodology

1. Data Preparation

II. Wind data

Hourly wind speed at station height:

YYYYMMDD	HH	DD	u [m/s]
			H = 34.8 m
20150101	1	210	4
20150101	2	200	3
20150101	3	190	4
20150101	4	200	4
20150101	5	210	4
20150101	6	190	5
20150101	7	190	6
20150101	8	210	5
20150101	9	220	5
20150101	10	210	6
20150101	11	210	6
20150101	12	220	7
20150101	13	200	7
.	.	.	.
.	.	.	.
.	.	.	.

$$v_2 = v_1 \cdot \left(\frac{Z_2}{Z_1}\right)^{\alpha}$$

- V_1 = Velocity at height Z_1
- V_2 = Velocity at height Z_2
- Z_1 = Height 1 (lower height)
- Z_2 = Height 2 (upper height)
- α = wind shear exponent

Wind shear exponent for built up area with mixed land use:
$\alpha = 0.3$

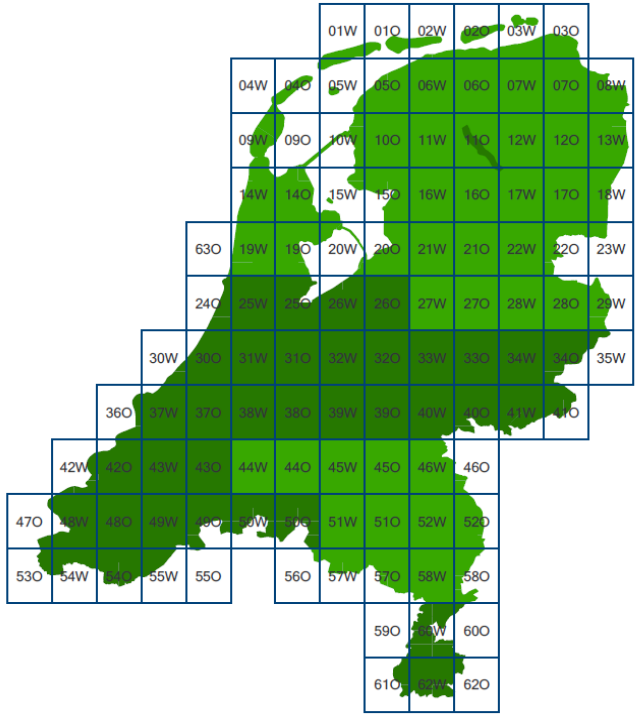
Hourly wind speed at turbine height:

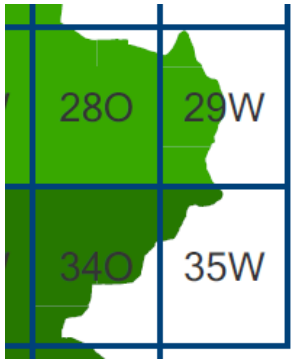
YYYYMMDD	HH	u [m/s]	u [m/s]	u [m/s]
		H = 53 m	H = 90 m	H = 142 m
20150101	1	4.5380	5.3194	6.0992
20150101	2	3.4035	3.9895	4.5744
20150101	3	4.5380	5.3194	6.0992
20150101	4	4.5380	5.3194	6.0992
20150101	5	4.5380	5.3194	6.0992
20150101	6	5.6726	6.6492	7.6240
20150101	7	6.8071	7.9790	9.1488
20150101	8	5.6726	6.6492	7.6240
20150101	9	5.6726	6.6492	7.6240
20150101	10	6.8071	7.9790	9.1488
20150101	11	6.8071	7.9790	9.1488
20150101	12	7.9416	9.3089	10.6736
20150101	13	7.9416	9.3089	10.6736
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

Methodology

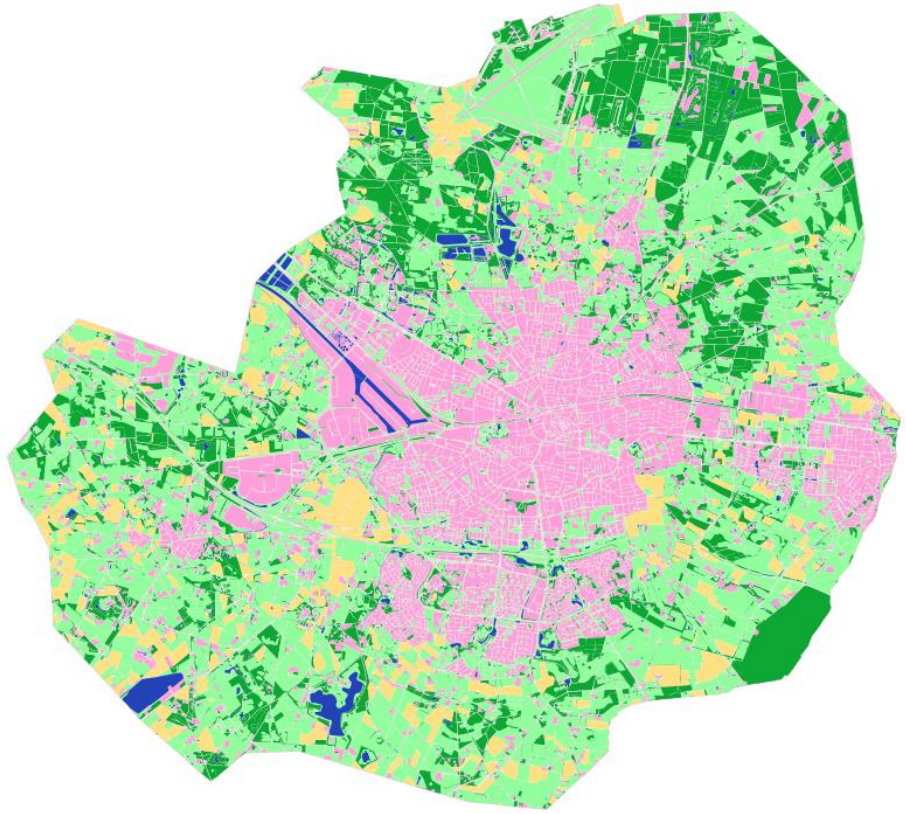
1. Data Preparation

III. Location data



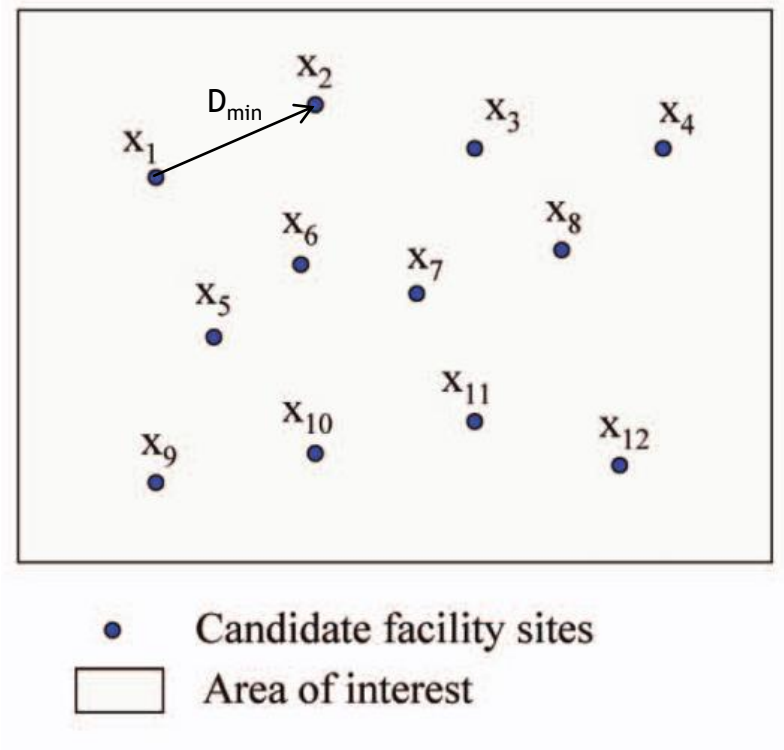


QGIS Trademark



Methodology

2. Problem definition



- Plant location problem
- Maximal covering location problem
- Undesirable facility location
- 2D packing problems

- X, Y coordinates
- Number of facilities
- Distance standard
- Minimizing cost

Methodology

3. Model definition

Cost of Energy (cost per kWh of energy produced):

$$CoE = \frac{Cost}{AEP}$$

Methodology

3. Model definition

$$CoE = \frac{Cost}{AEP}$$

$$T\,\{t1\,(Vi, Vr, Vo, Pr, D, H),\quad t2\,(Vi, Vr, Vo, Pr, D, H),\quad t3\,(Vi, Vr, Vo, Pr, D, H)\}$$

$$A\,\{(i, j), where\ \ i = 1,2, \ldots m, j = 1,2, \ldots n\,\}\ set\ of\ X, Y\ coordinates\ for\ the\ study\ area$$

$$Cost\,(N, Pr)$$

$$AEP(N, T, v)$$

$$N(A)$$

Methodology

3. Model definition

Model parameters:

1. Turbine type and number
2. Turbine interdistance and location
3. Wind speed
4. Shape and size of the available land

Methodology

4. Grid representation

- Each grid cell is a potential location for turbine placement

1, 1	1, 2	1, 3	1, 4	1, 5	1, 6
2, 1	2, 2	2, 3	2, 4	2, 5	2, 6
3, 1	3, 2	3, 3	3, 4	3, 5	3, 6
4, 1	4, 2	4, 3	4, 4	4, 5	4, 6
5, 1	5, 2	5, 3	5, 4	5, 5	5, 6
6, 1	6, 2	6, 3	6, 4	6, 5	6, 6

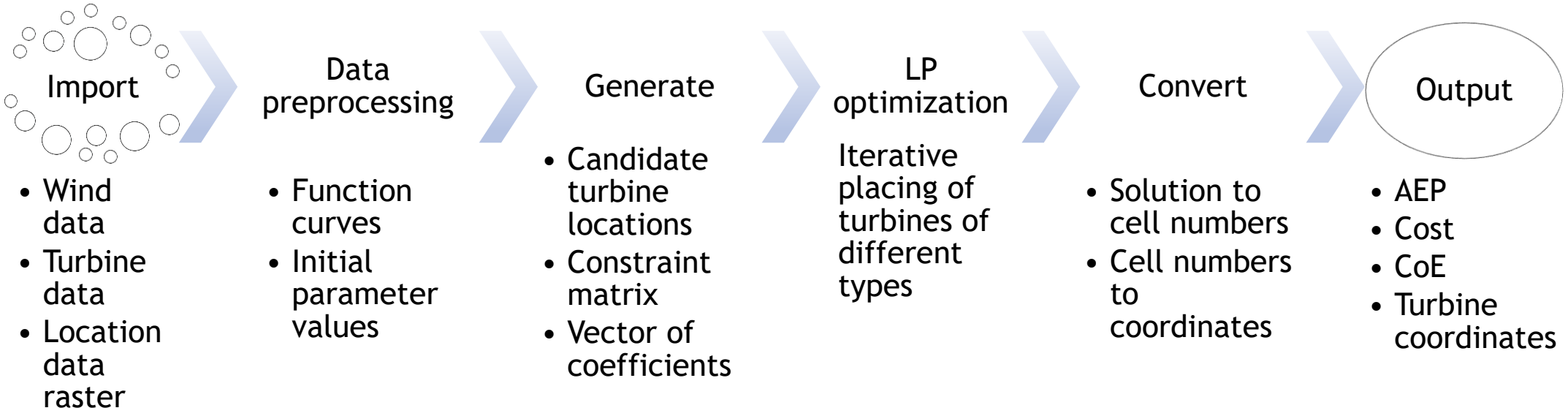
$5D_1$

$5D_2$

$5D_3$

Methodology

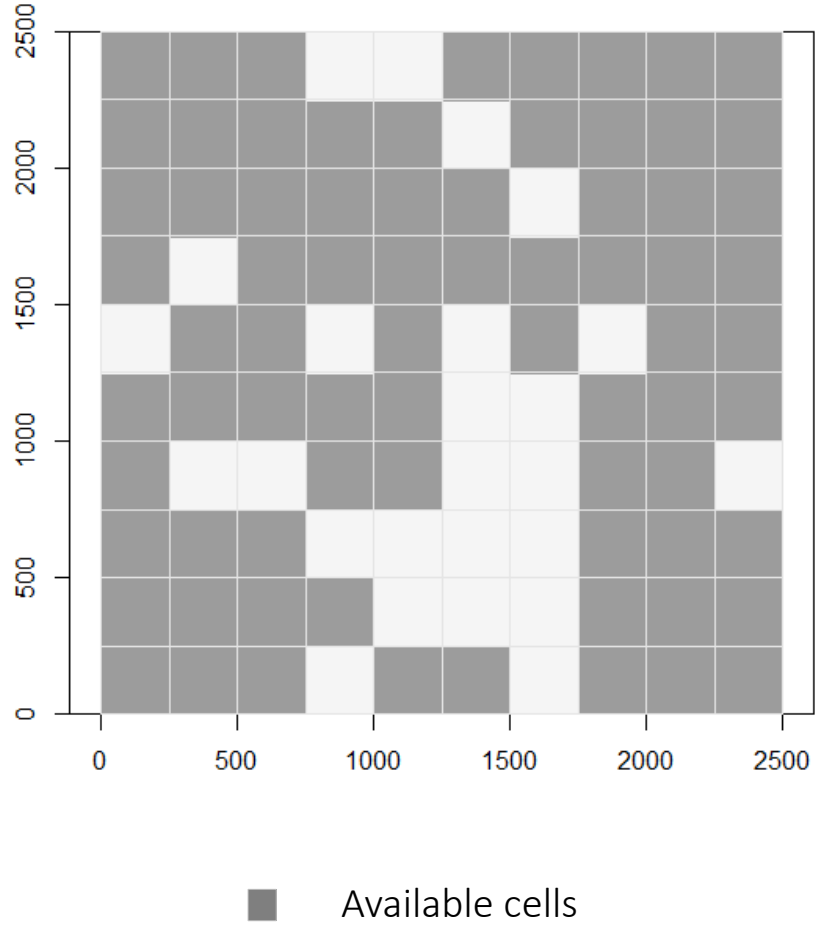
5. Algorithm Framework



Implementation and results

Import

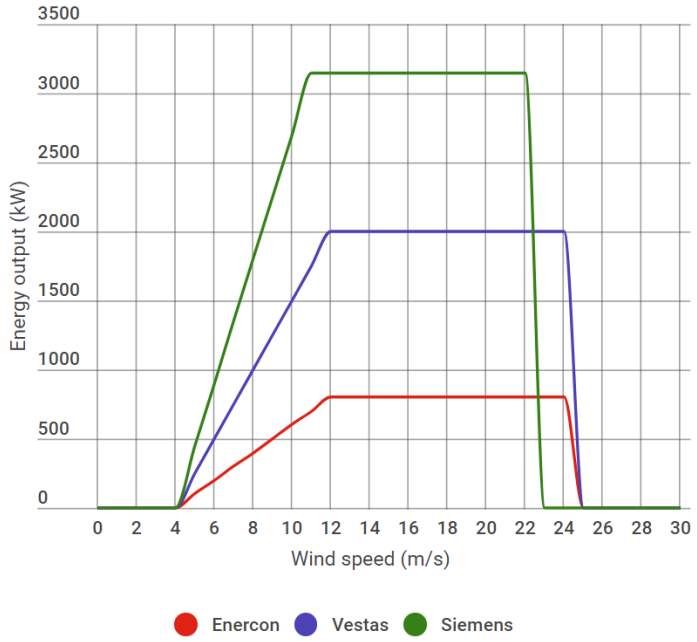
- Wind data
- Turbine data
- Location data raster



Implementation and results

Data preprocessing

- Function curved
- Initial parameter values

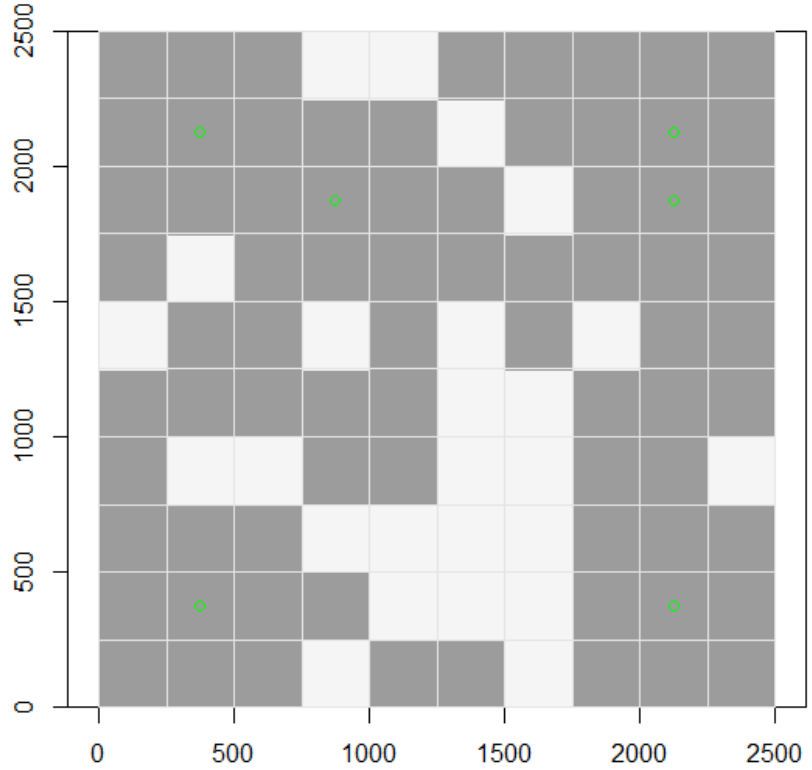


N = 1	Enercon	Vestas	Siemens
Cost (€)	800 000	2 000 000	3 150 000
AEP (kW)	2 477 536	7 531 257	14 363 679

Implementation and results

Generate

- Candidate turbine locations
- Constraint matrix
- Vector of coefficients



Implementation and results

Generate

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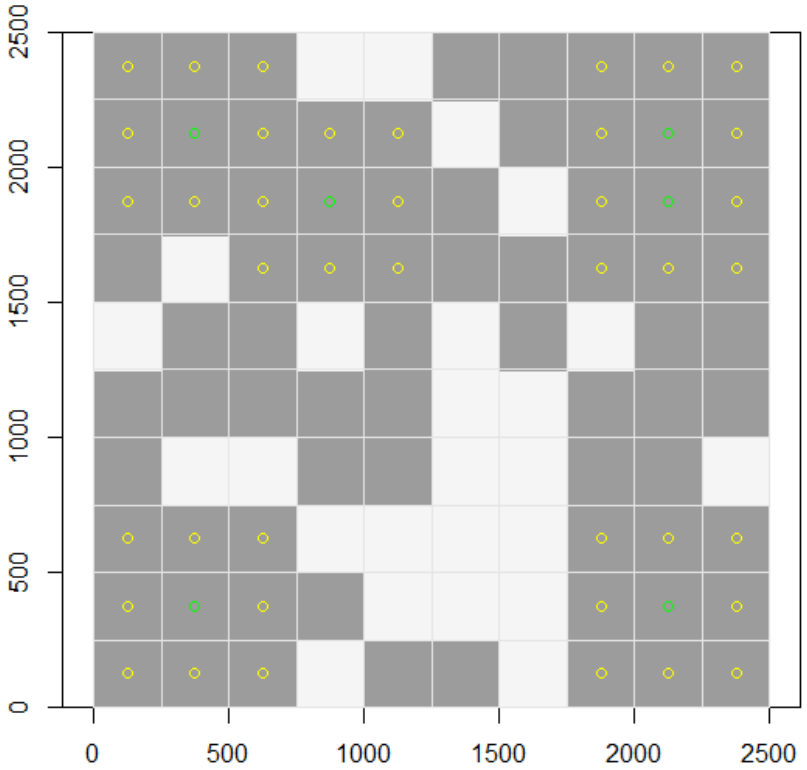
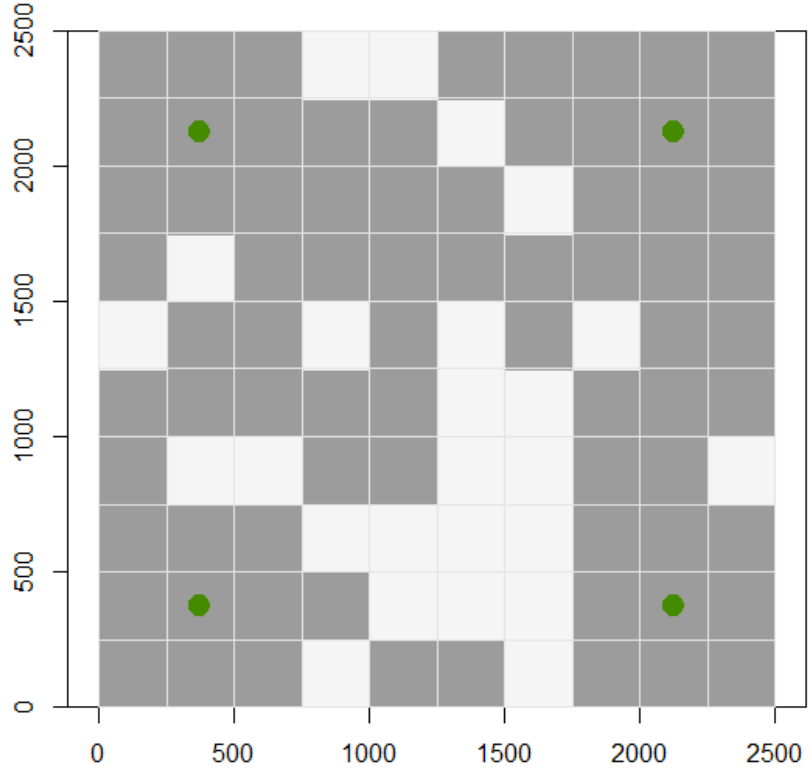
- Vector of coefficients



Implementation and results

LP optimization

- Iterative placing of turbines of different types



Implementation and results

LP optimization

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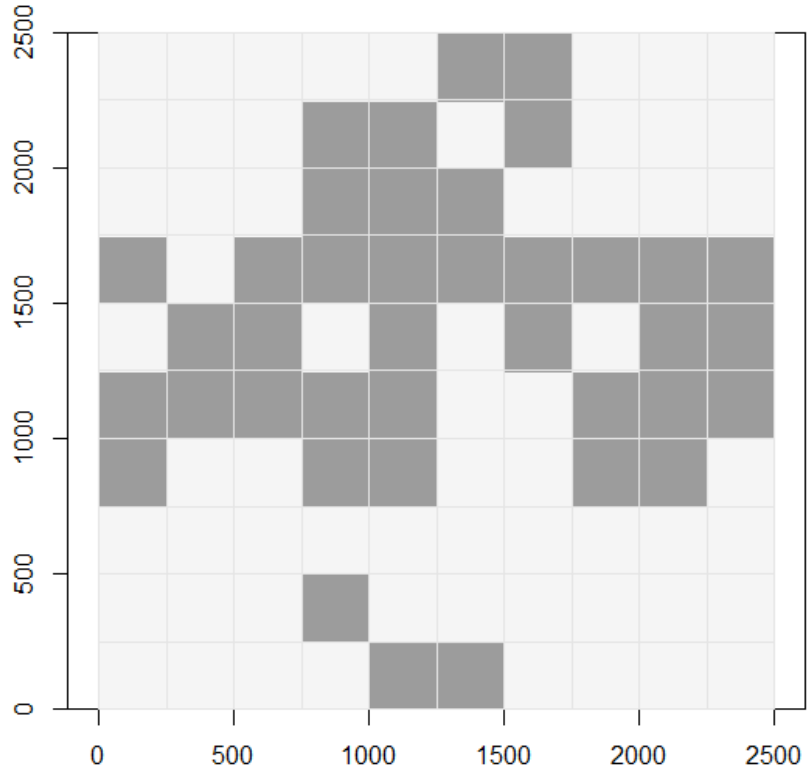

Implementation and results

LP optimization

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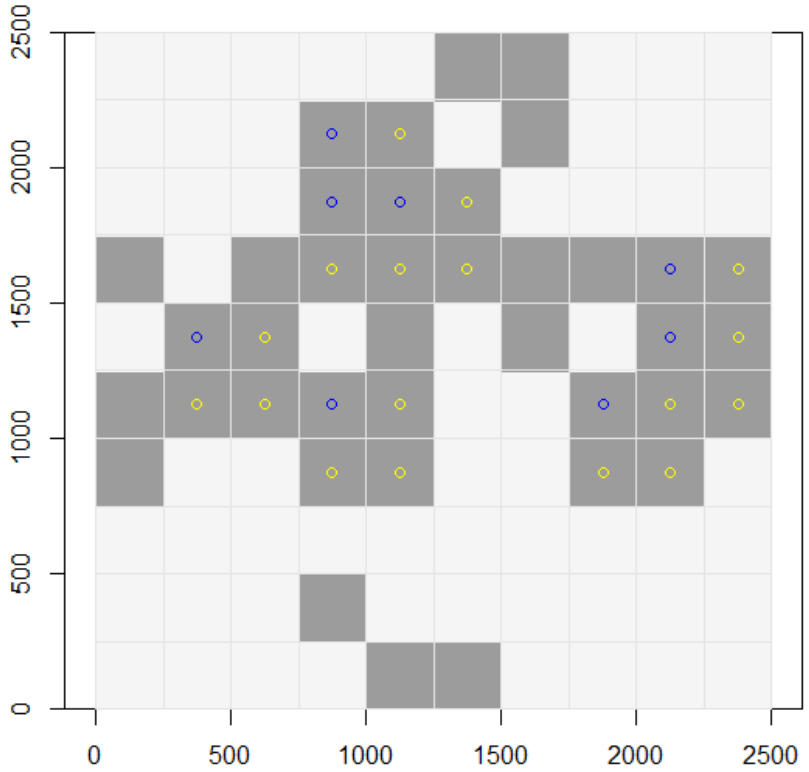

Implementation and results

LP optimization

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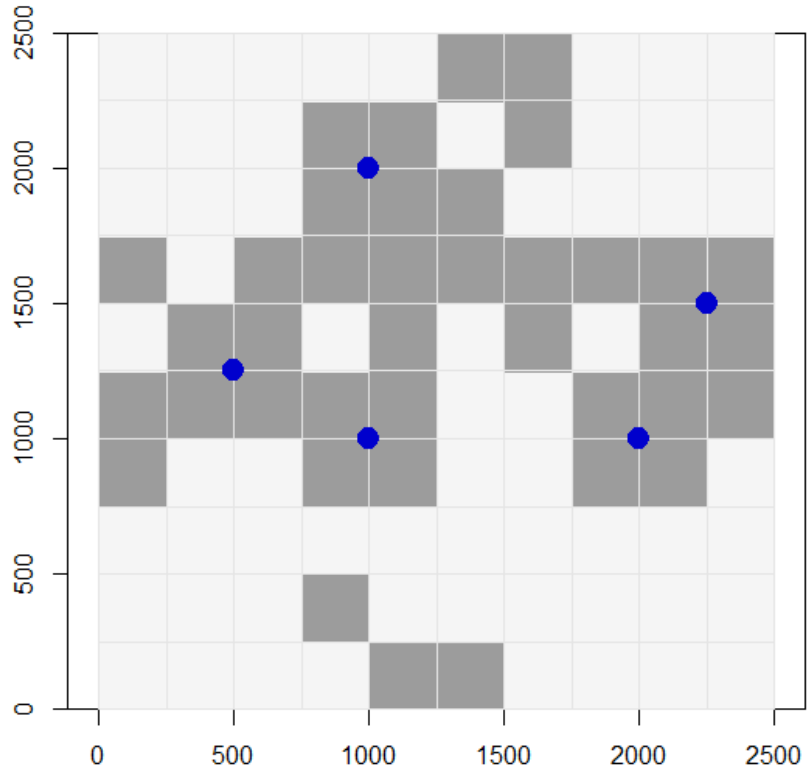

Implementation and results

LP optimization

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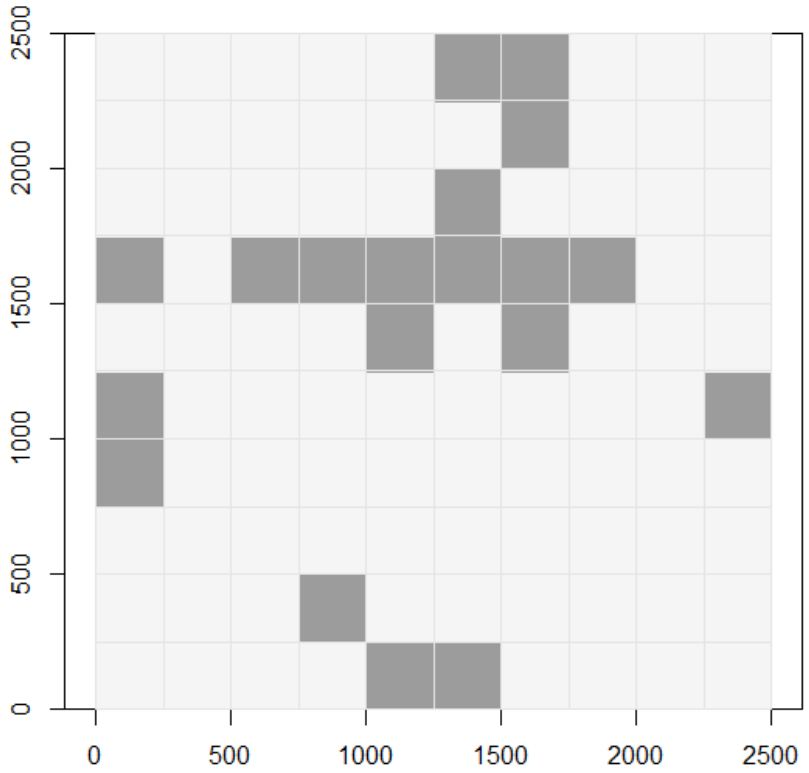
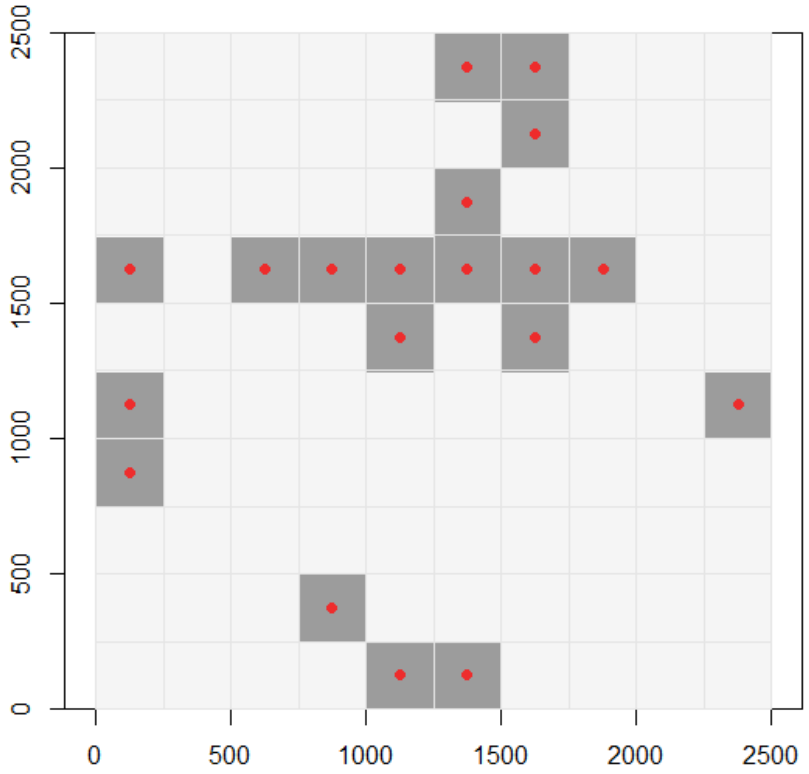


Implementation and results

LP optimization

- Iterative placing of turbines of different types



Implementation and results

LP optimization

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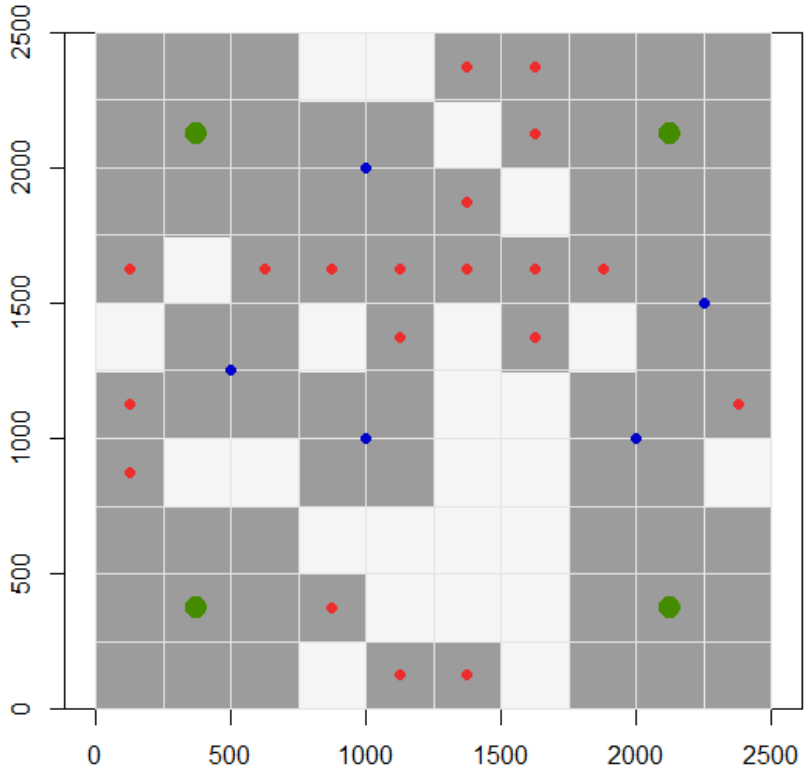
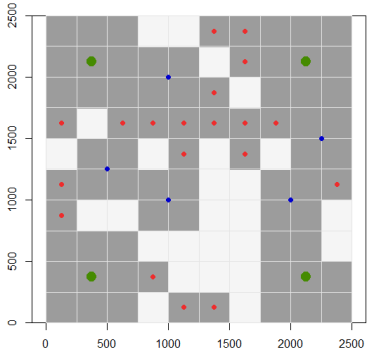


Implementation and results

Output

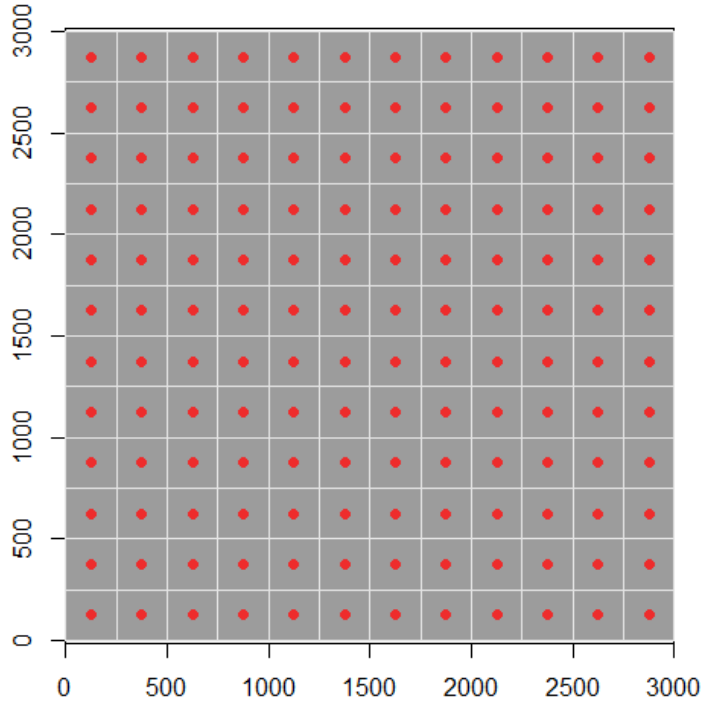
- AEP
- Cost
- CoE
- Turbine coordinates

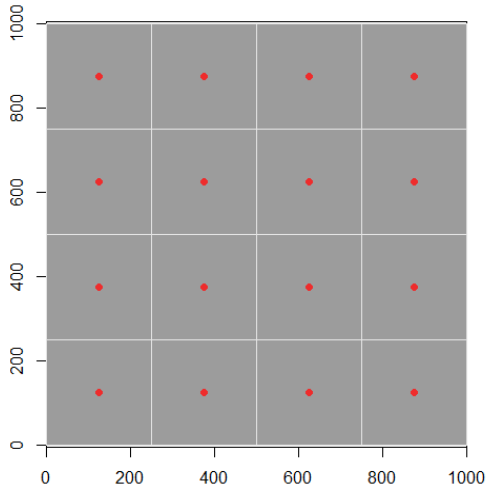


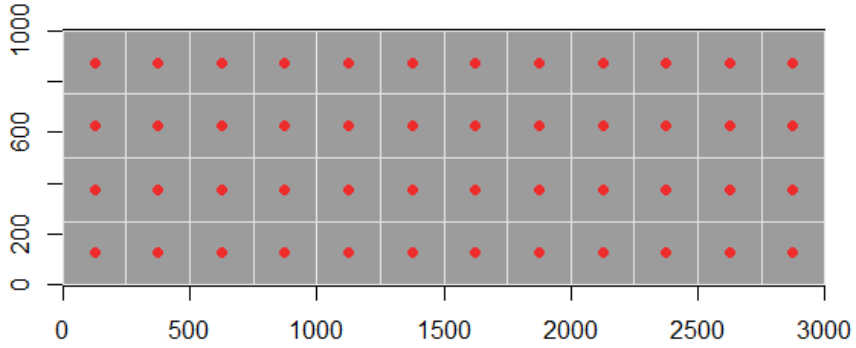
N (E)	19
N (V)	5
N (S)	4
N_{tot}	28
Cost (€)	34 944 538
AEP (kW)	142 346 303
CoE (€/kW)	0.247422

Implementation and results

1. Algorithm validation – One turbine type



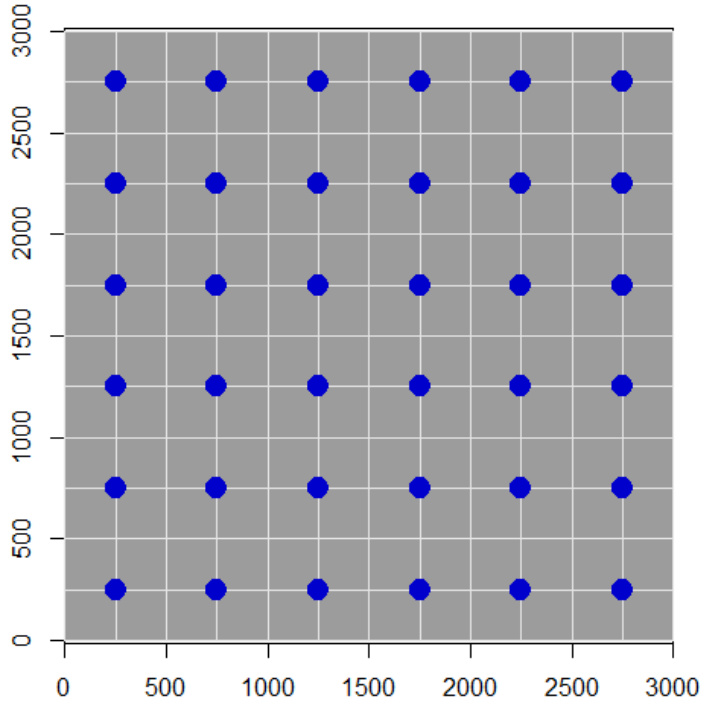


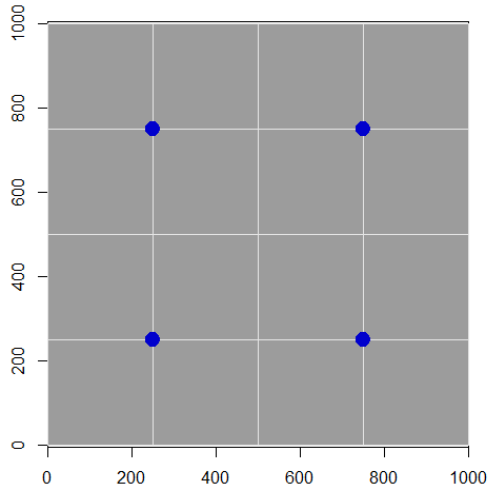


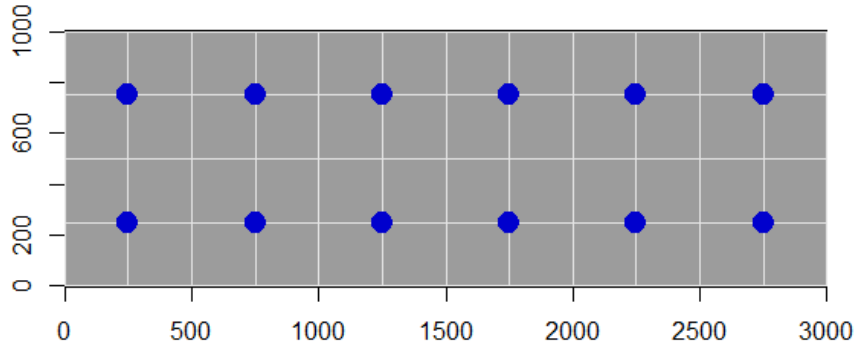
Enercon

Implementation and results

1. Algorithm validation – One turbine type



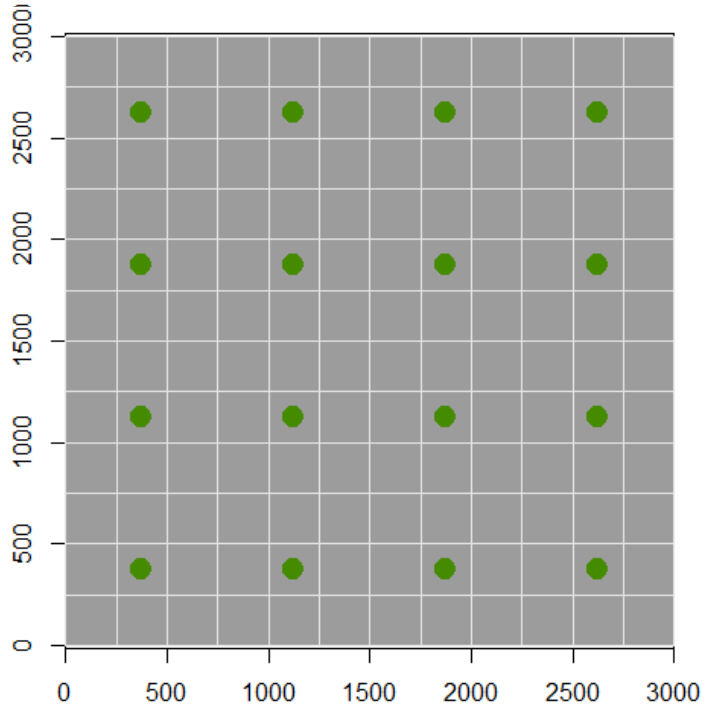


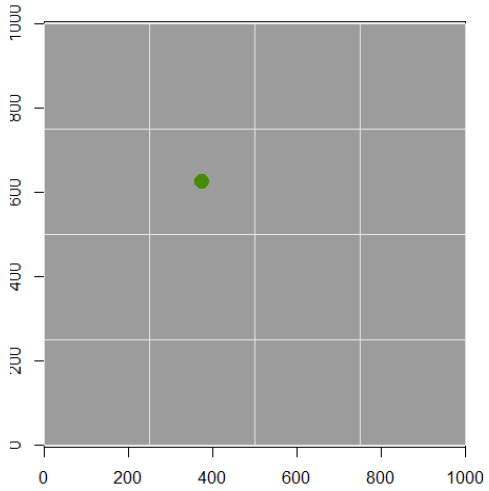


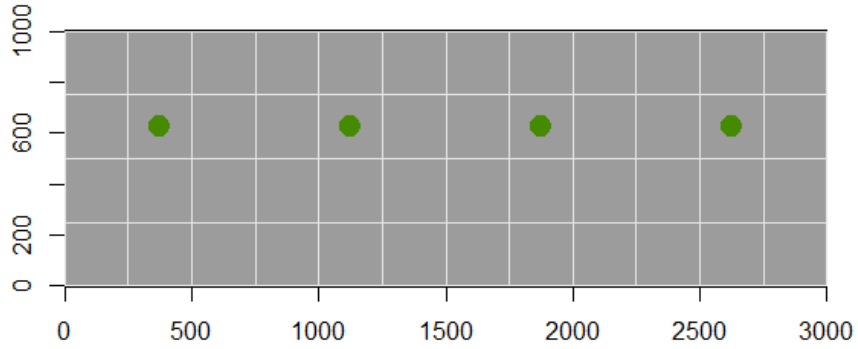
Vestas

Implementation and results

1. Algorithm validation – One turbine type



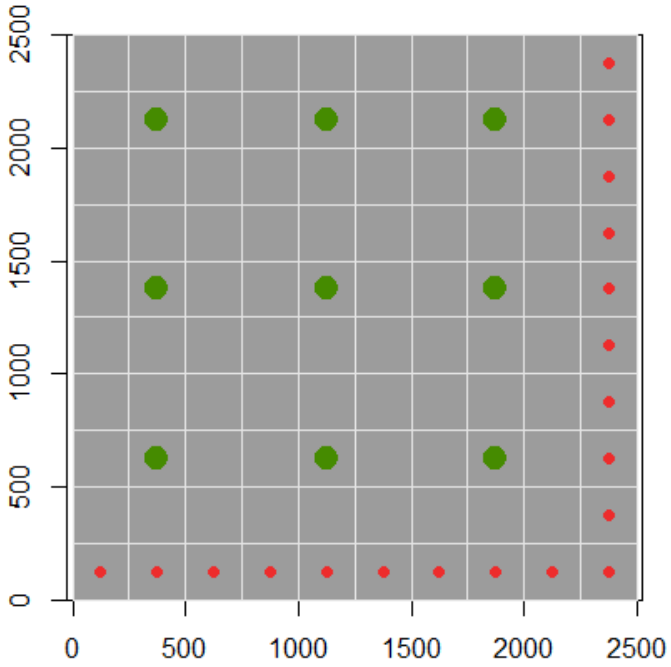


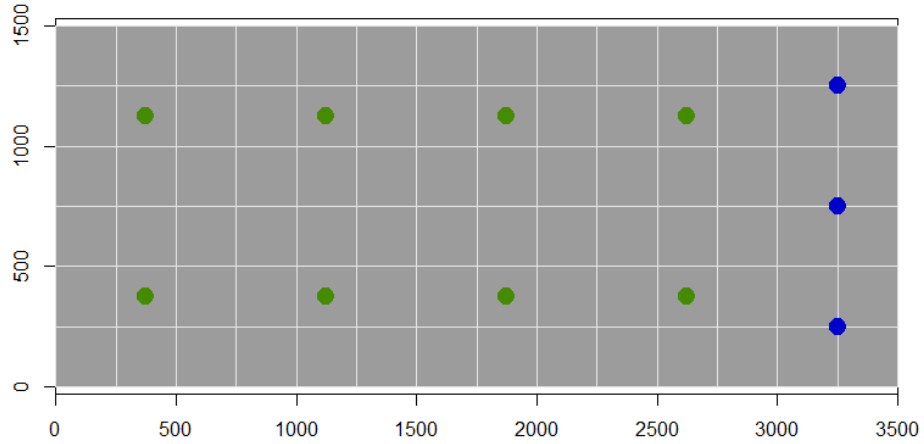


Siemens

Implementation and results

2. Algorithm validation – Three turbine types

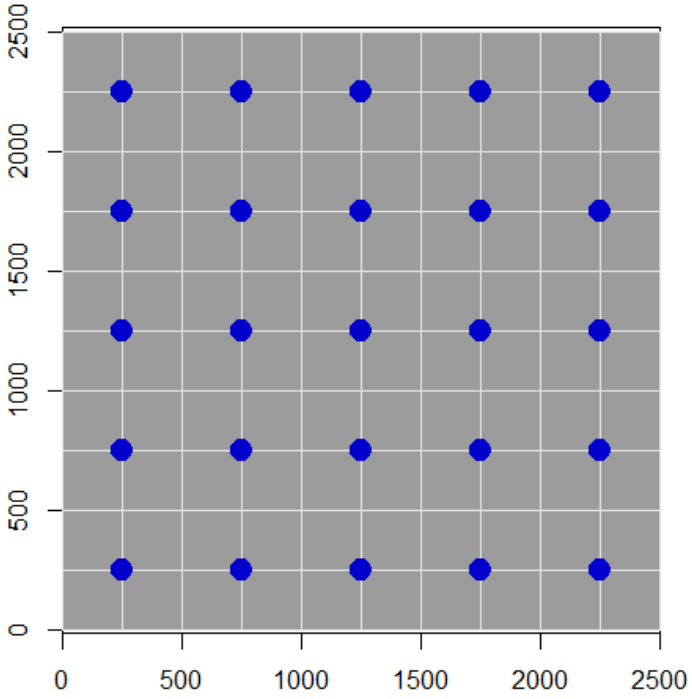


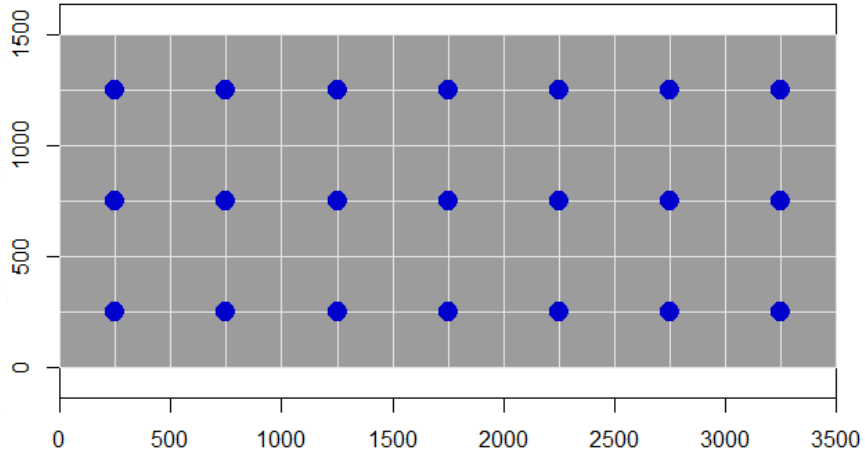


Enercon Vestas Siemens

Implementation and results

2. Algorithm validation – Three turbine types

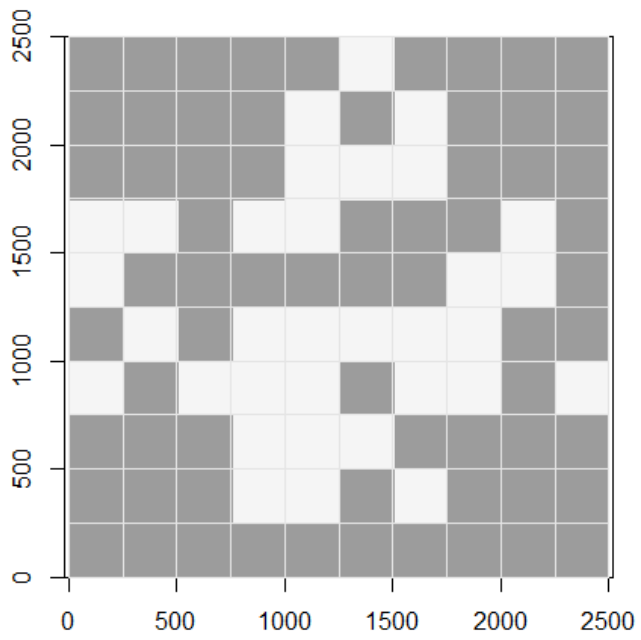


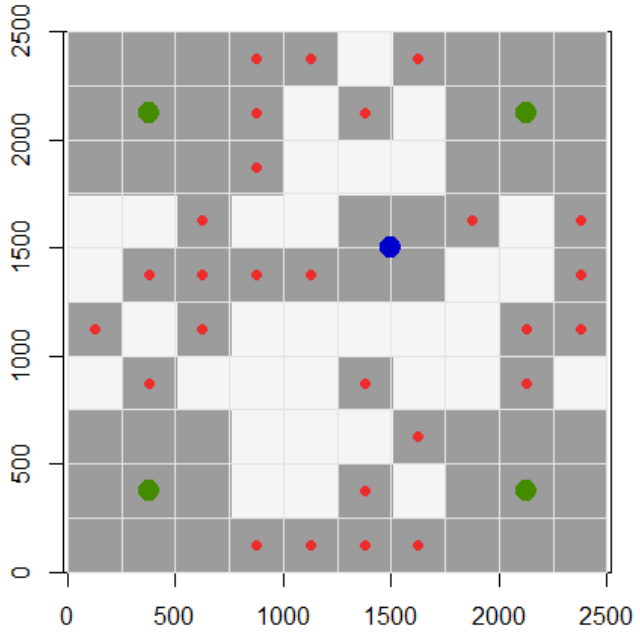


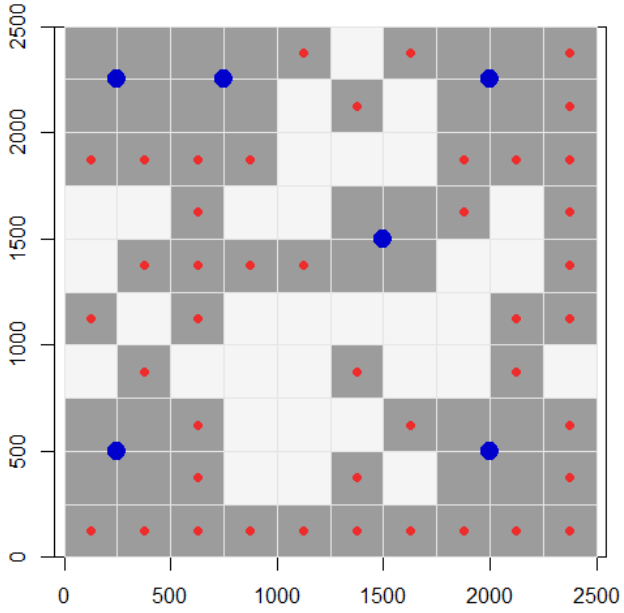
Enercon Vestas Siemens

Implementation and results

3. Algorithm validation – Three turbine types and area with forbidden zones



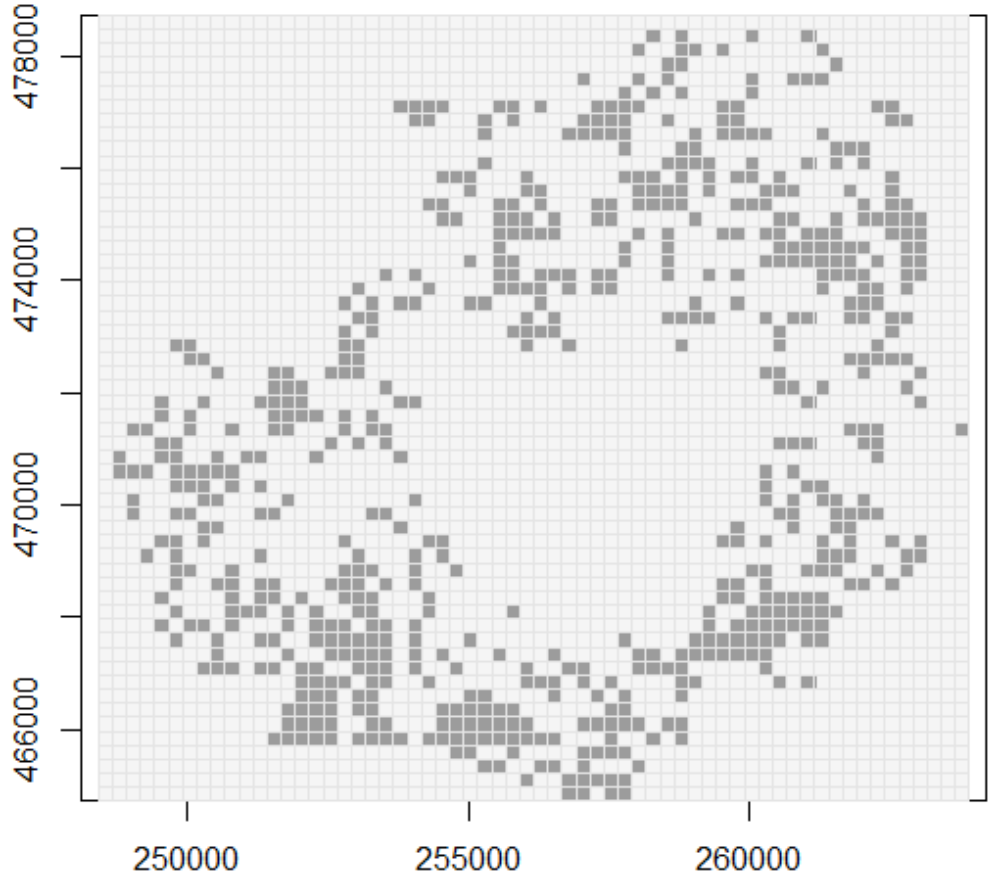




Enercon Vestas Siemens

Implementation and results

4. Application to study area



Implementation and results

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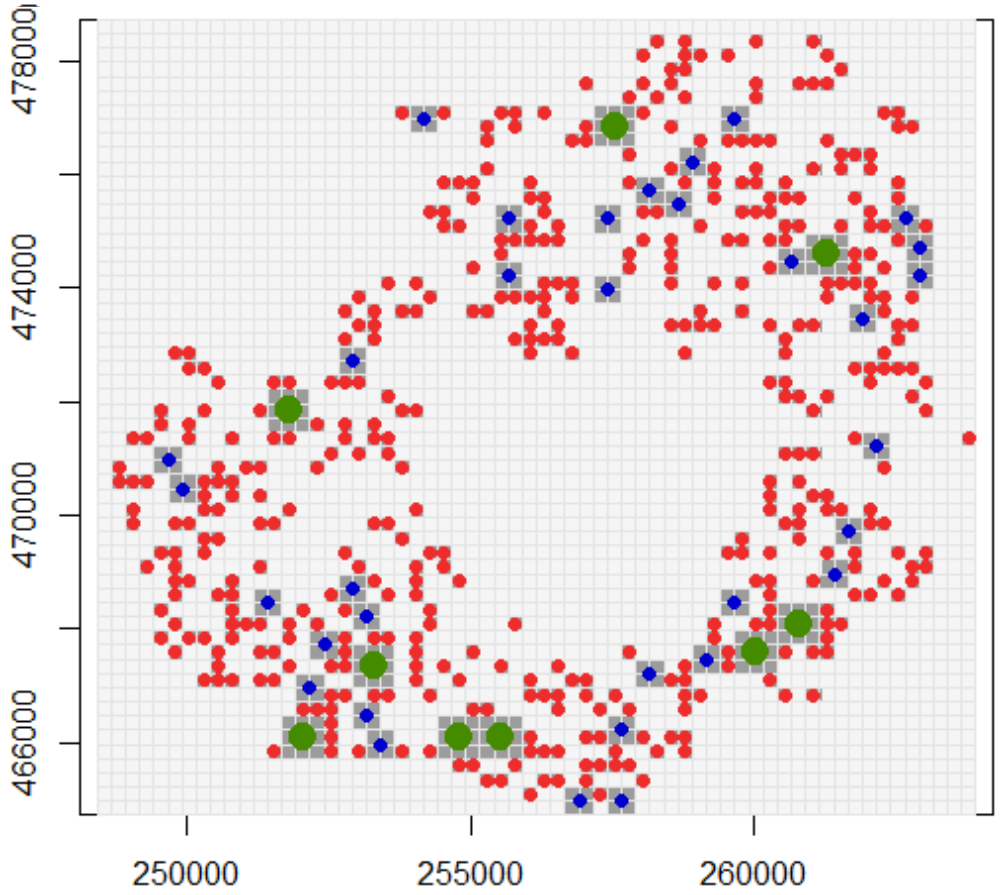
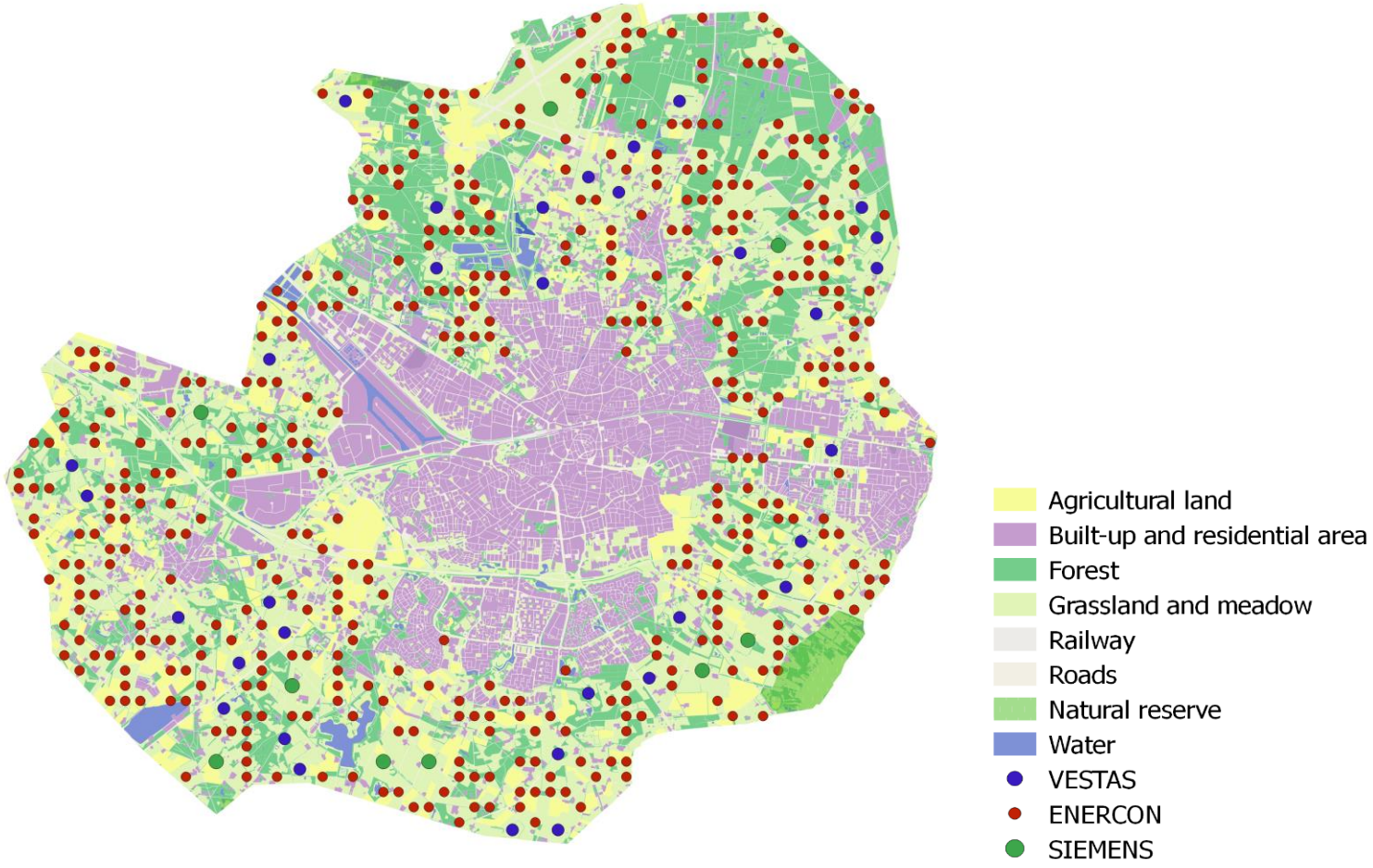


Implementation and results

4. Application to study area



N (E)	445
N (V)	33
N (S)	9
N_{tot}	487
Cost (€)	311 748 515
AEP (kW)	1 480 308 280
CoE (€/kW)	0.210597

Discussion

- Solution time
- Accuracy of parameter calculation
- Turbine performance results (using one or three turbine types)
- Algorithm search
- Rasterization process and scale issue

Conclusion and outlook

To what extent are the research question answered?

1. How to formulate an objective function in order to maximize the AEP (Annual Energy Production)?
2. Which multi-objective optimization techniques are best for a wind farm layout scenario?
3. Should this model account for turbine wakes, and how can this effect be incorporated into the model?
4. Which optimization algorithm will provide the best trade-off between accuracy of the output result and computing effort?
5. How to assess the quality of the model?

Conclusion and outlook

- The implemented approach showed its applicability for the given optimization problem
- Binary integer linear programming and the use of GIS posses a great potential to aid in the process of development of wind farm projects
- Tool for preliminary screening in wind farm siting at a large scale
- Improvements of the developed procedure are possible, in terms of parameter setting used, the complexity of the objective function and the optimization method applied
- Algorithm developed here could be incorporated into the already existing Desktop-based or Web-based applications

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THANK YOU FOR YOUR ATTENTION!

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