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Optimization of Mooring Configurations for Minimized Wake Effects in Floating Wind Farms (ASYMoor)

Yuksel Rudy Alkarem

Presentation Outline

Introduction

- problem statement
- concept description

Methodology

- mooring, wake, and optimization models description
- parametric description
- Modeling flowchart

Results

- Parametric Analysis
- Turbine Clustering
- Humboldt case study

Conclusion & Future Work

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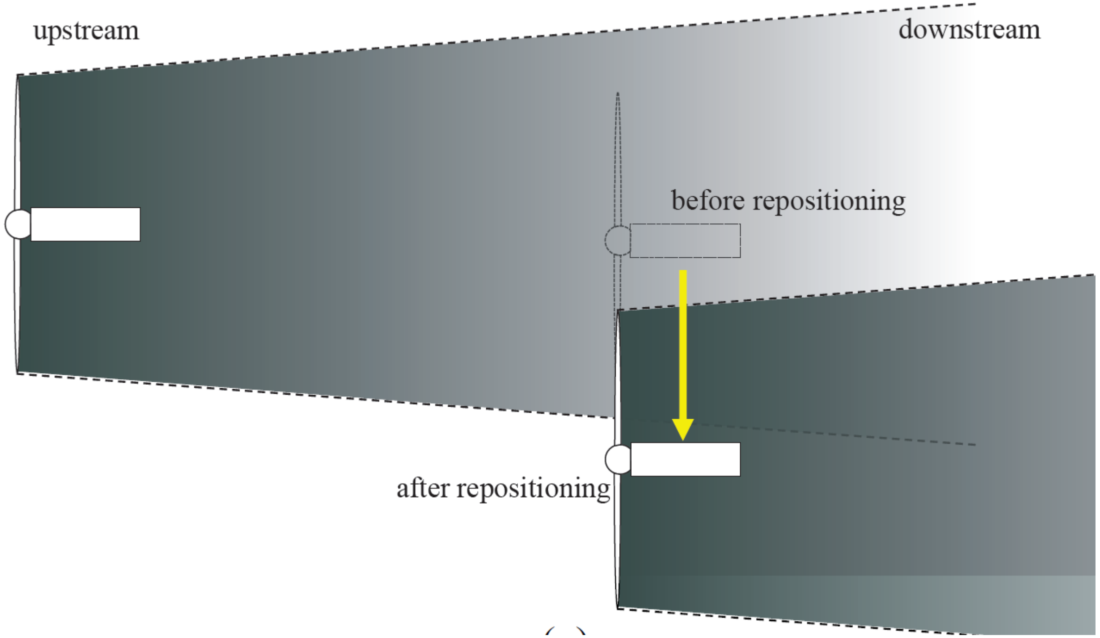
Introduction

Focus	Problem Description	Proposed Solution
Regular Wind Farm Layout Design	Power Loss due to Wake Effects	Simplified Mooring design
+	+	+
Farm-level Mooring Design	Complex Mooring Systems	Minimum Wake Effects

Concept: ASYMoor

The **Asymmetry** in the Mooring lines between upstream and downstream produce wake steering



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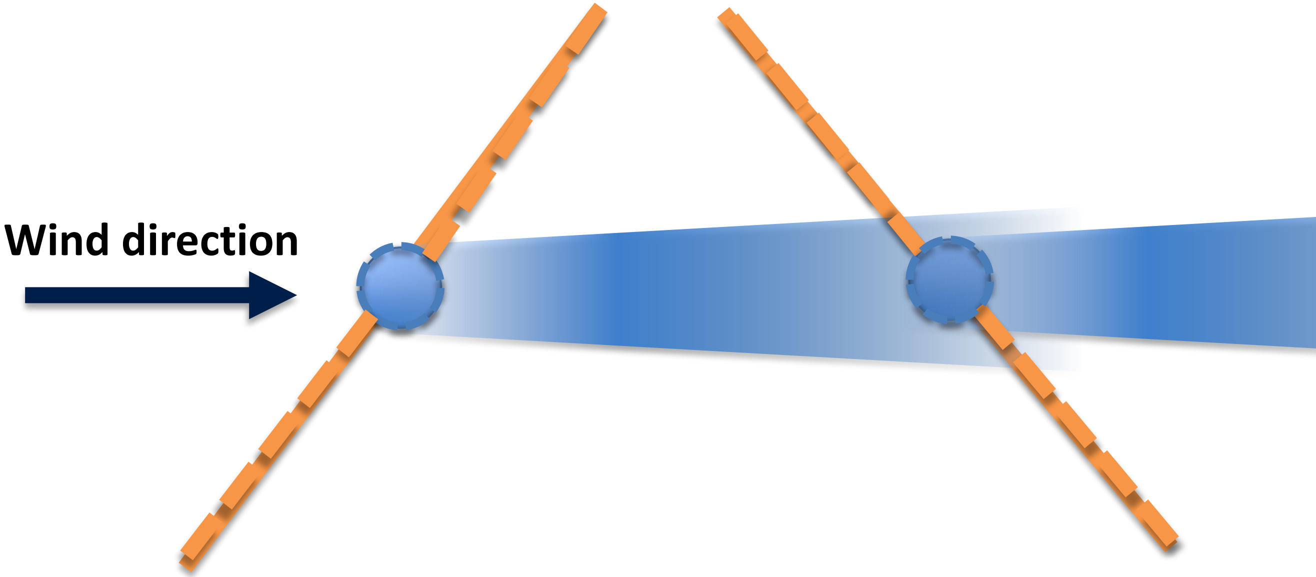

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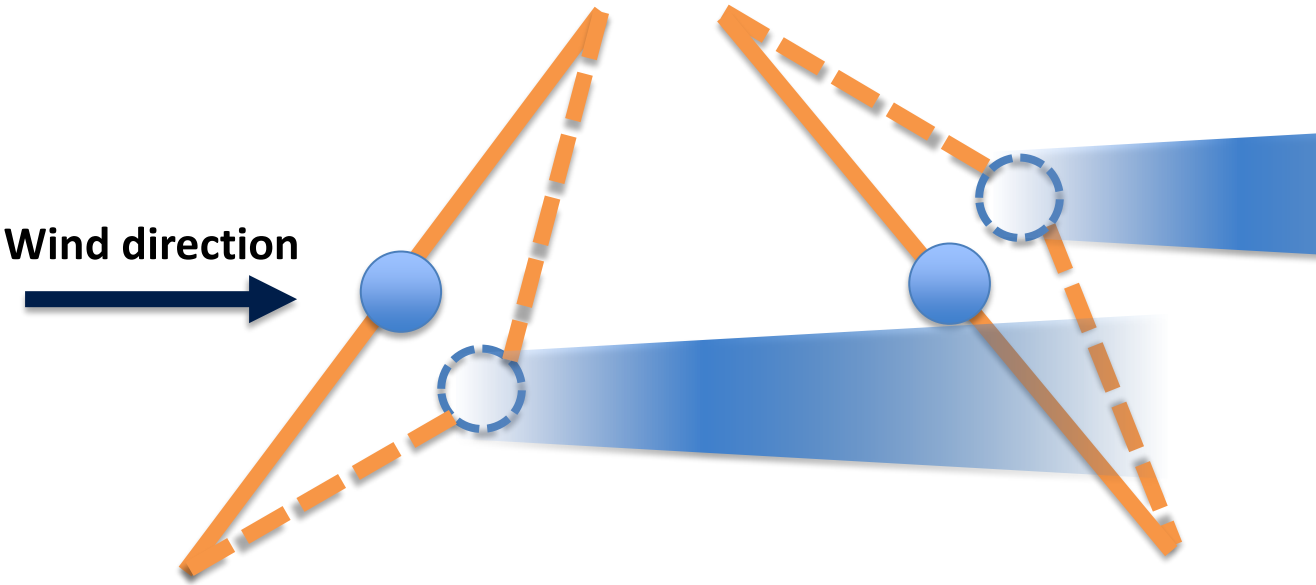


Methodology

ASYPY =

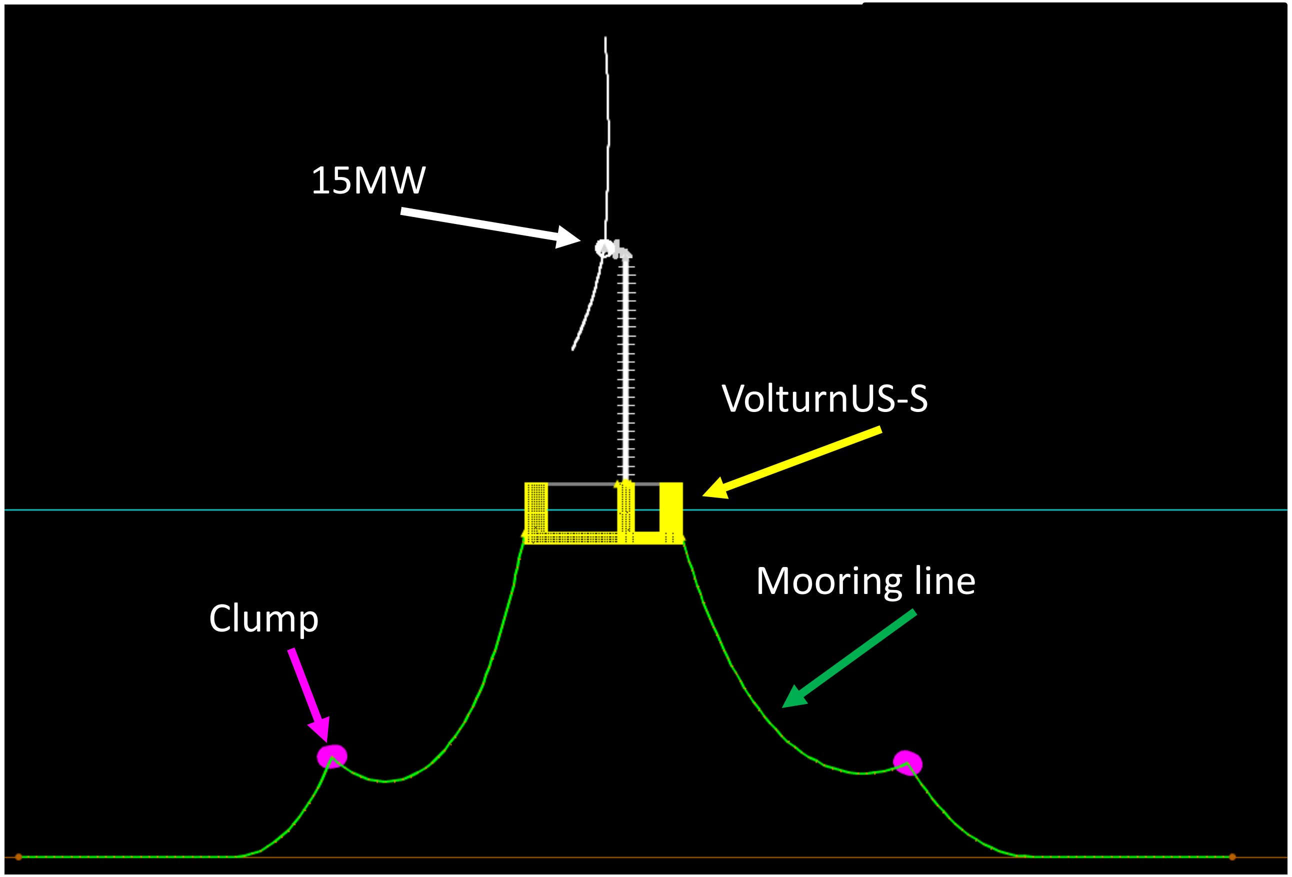
OrcaFlex Python API

+

Floris

+

Optuna



Platform: UMaine VolturnUS-S Reference Platform (Allen et al. 2020)
Turbine: IEA 15-MW Reference Turbine (Gaertner et al. 2020)

Wake Model

- open-source FLOw Redirection and Inductive in Steady State (FLORIS v3.0.0)

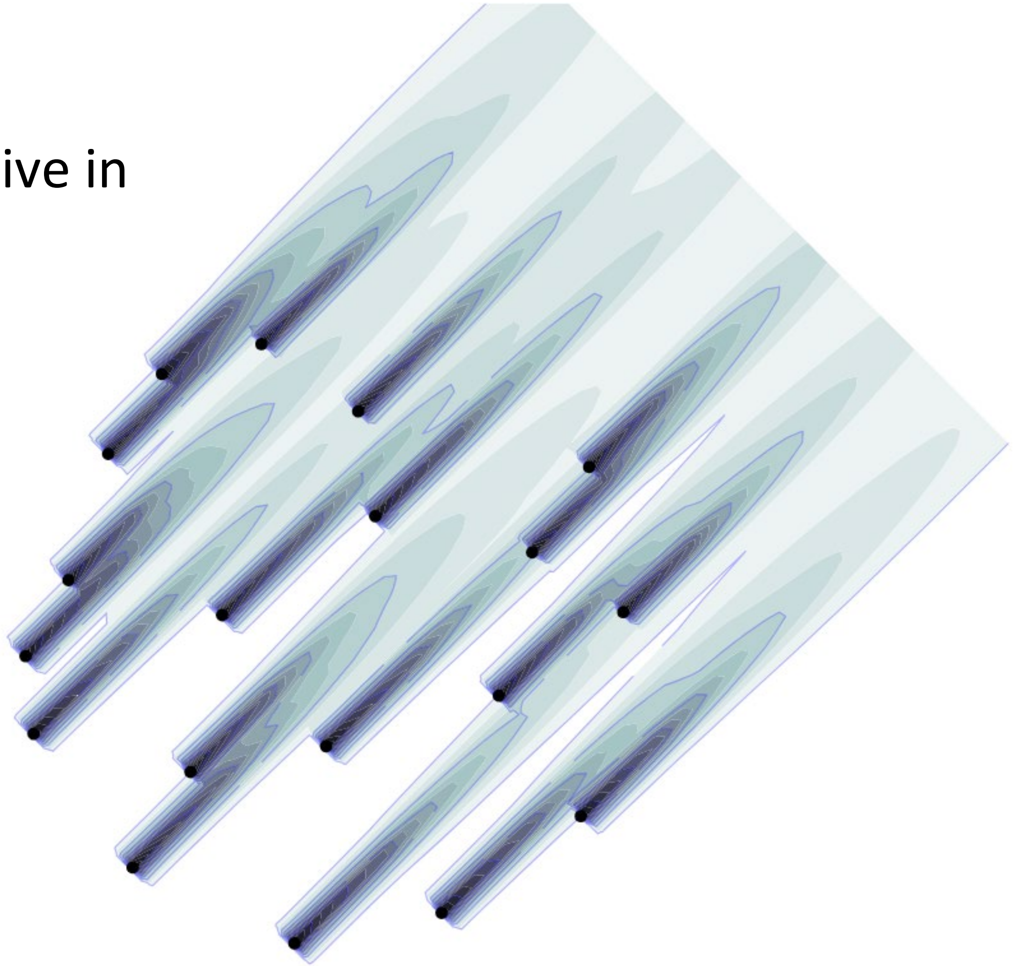
Wake deflection: Gaussian (Bastankhah and Porté-Agel 2014)
Velocity model: Gaussian (Niayifar and Porté-Agel 2015)
Combination model: SOSFS (Katic, Højstrup, and Jensen 1986)

$$I_\infty = 6\%$$

$$k_a = 0.10, k_b = 0.004$$ wake expansion coefficients

$$\alpha_w = 0.58, \beta_w = 0.077$$ near-far wake coefficients

no lateral wake deflection



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Optimization Model

- Optuna Package [A hyperparameter optimization framework]

(Watanabe 2023)

Tree-structured Parzen Estimator (TPE) Sampler algorithm

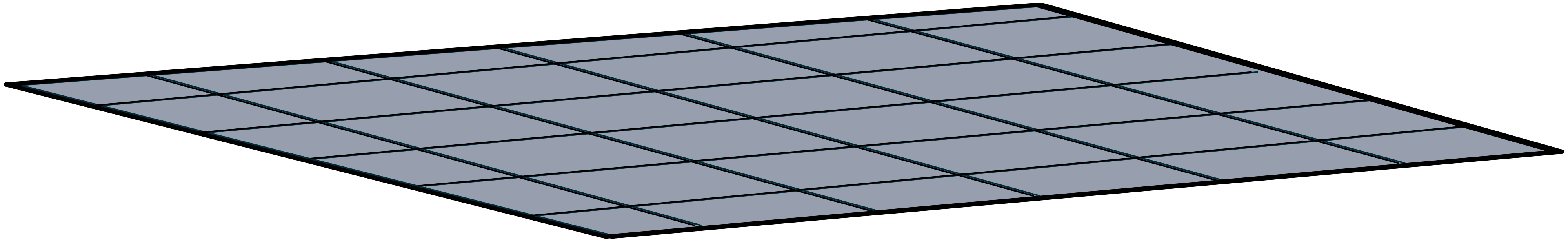
Optuna: A hyperparameter optimization framework. Available online: https://optuna.readthedocs.io/en/stable/index.html

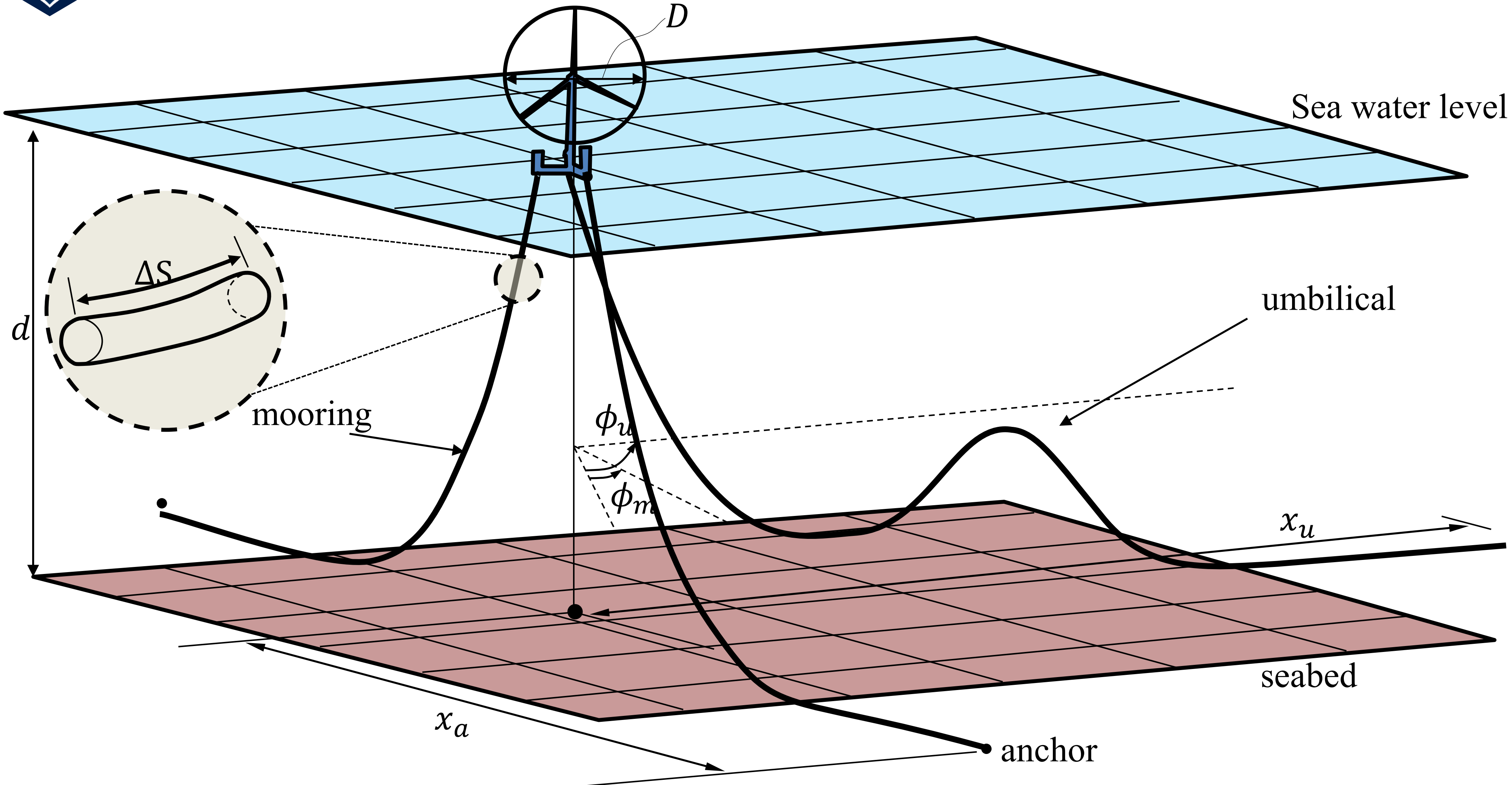
Study Scope + Key Assumptions

- Steady State Analysis
- Mooring and anchor forces not analyzed
- Wave current actions not included
- Main driving force = thrust force
- No farm control
- No seabed slope

Parametric Description

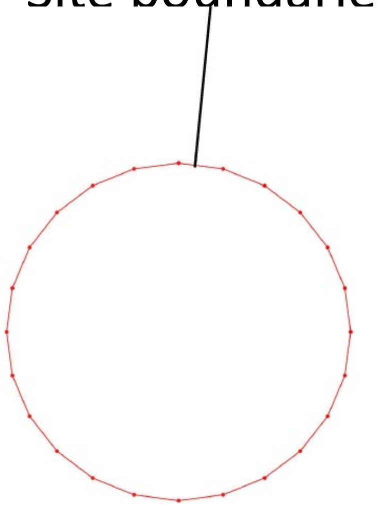
Category	parameter	symbol
	layout orientation	θ_F
farm	layout skewness ratio	S_F
	spacing ratio	S
environmental	water depth	d
	number of mooring lines	N_m
	fairlead horizontal distance	x_f
	fairlead vertical distance	z_f
	anchor horizontal distance	x_a
mooring	anchor vertical distance	x_f
	catenarity	β
	mooring segment length	ΔS
	mooring orientation	ϕ_m
	mooring sectional type	-
	umbilical orientation	ϕ_u
	bend stiffener range	z_{bs}
umbilical	umbilical horizontal reach	x_u
	umbilical sectional lengths	ℓ_1, ℓ_2
	umbilical sectional types	-




D
Sea water level
ΔS
d
umbilical
mooring
ϕ_u
ϕ_m
x_u
seabed
x_a
anchor

Site-specific

- Site boundaries



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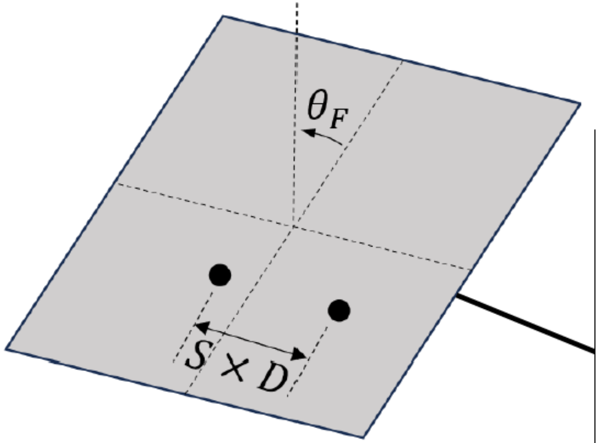


Farm-level properties

(Gonzalez-Rodriguez et al. 2022)

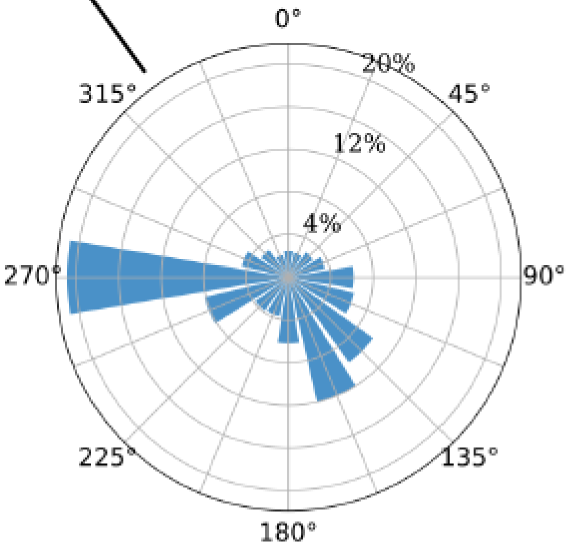
Site-specific

- Site boundaries

Farm-level properties

Turbine fixed location

Wind resources



(Mahfouz and Cheng 2023)

Site-specific

- Site boundaries

Wind resources

Farm-level properties

Turbine model

Turbine fixed location

Farm model

Compute AEY

Baseline AEY

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Site-specific

- Site boundaries

Farm-level properties

Turbine fixed location

Wind resources

Turbine model

Farm model

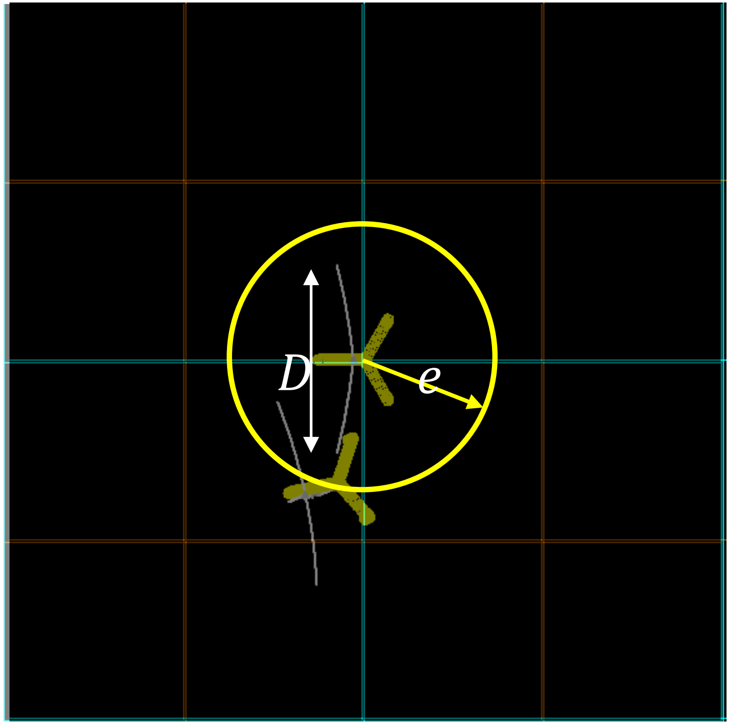
Mooring

IA-fixed properties

Find catenary configuration

Constraints

Excursion to rotor diameter: e/D



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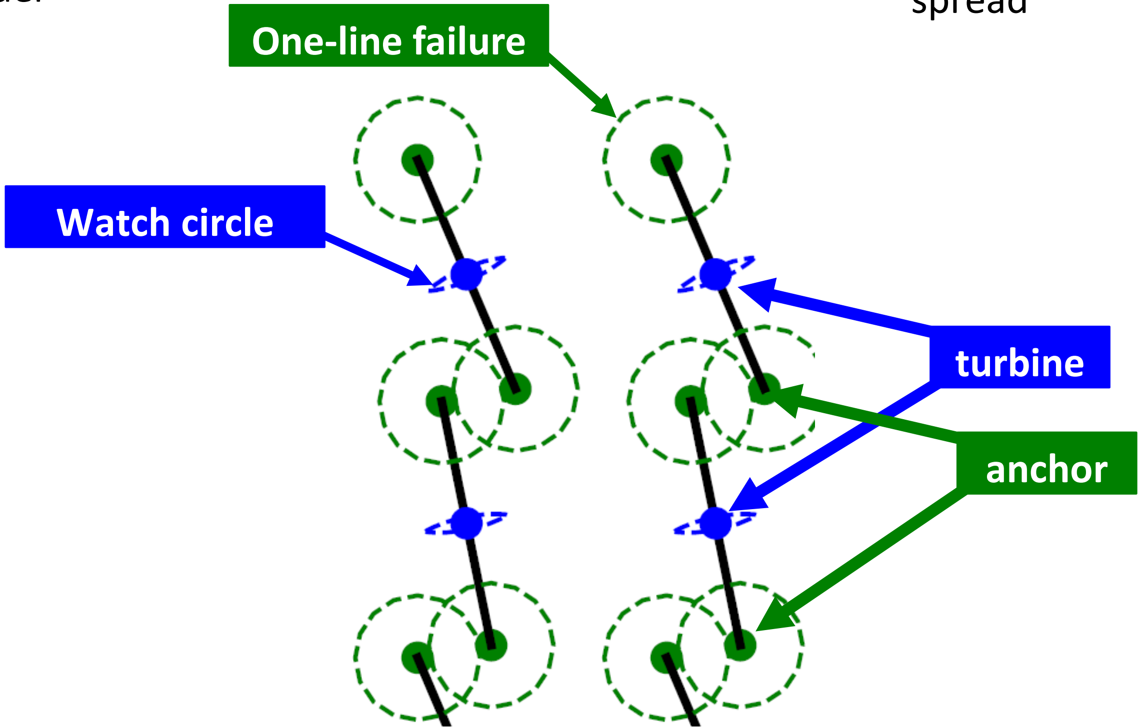
Maximum anchor spread



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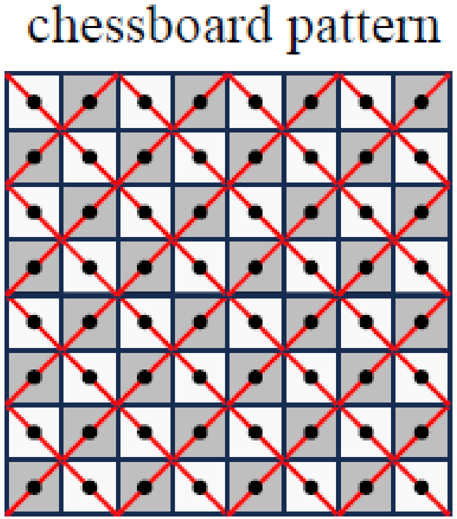
ASYMoor Optimization

IA-variables properties

Orientation method

a)



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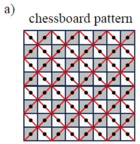

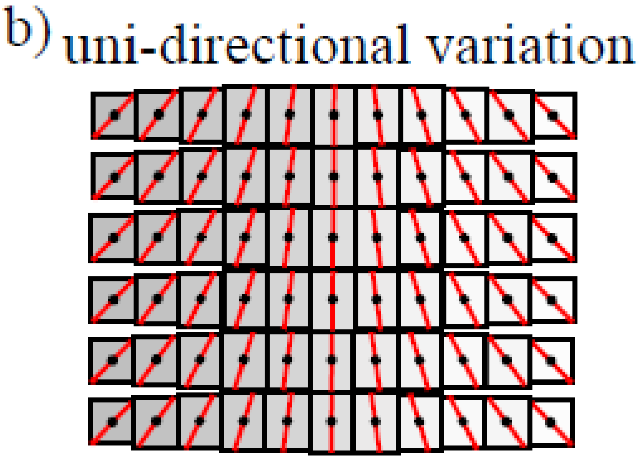

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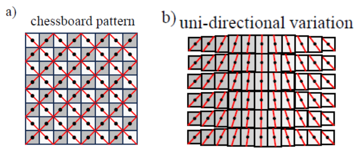

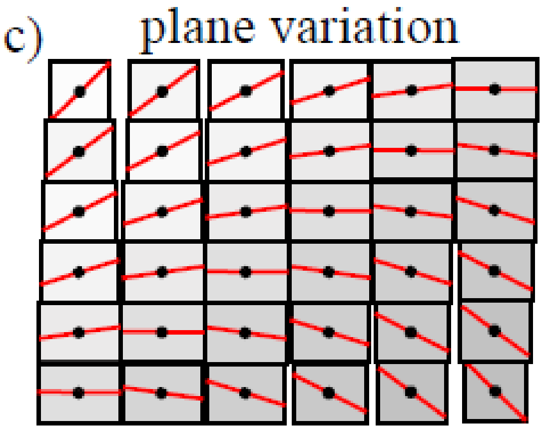

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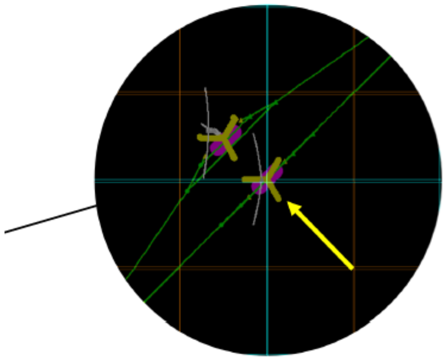
Orientation method

Loop over wind speeds/wind directions

Compute Thrust at turbine location

Compute excursion



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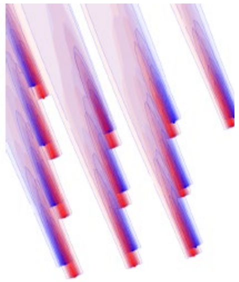

Loop over wind speeds/wind directions

Compute Thrust at turbine location

Find flow field

Relocate turbines

Compute excursion

Compute AEY

Baseline AEY

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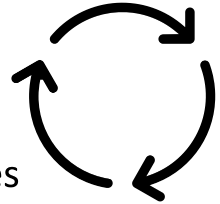

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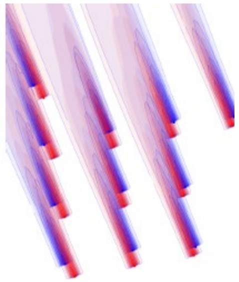
Compute excursion



Compute AEY

Baseline AEY

ASYMoor AEY

Results

Parametric Analysis

Turbine Clustering and Shared Anchors

Humboldt Case Study

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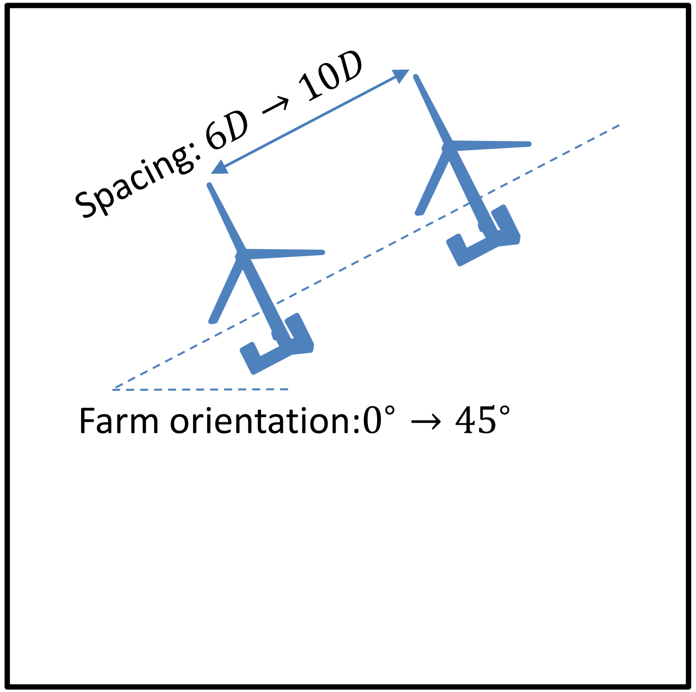
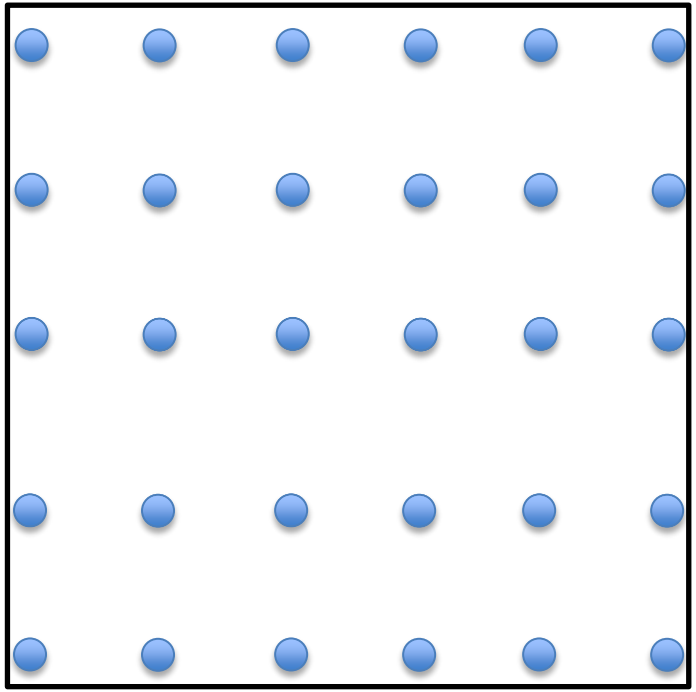
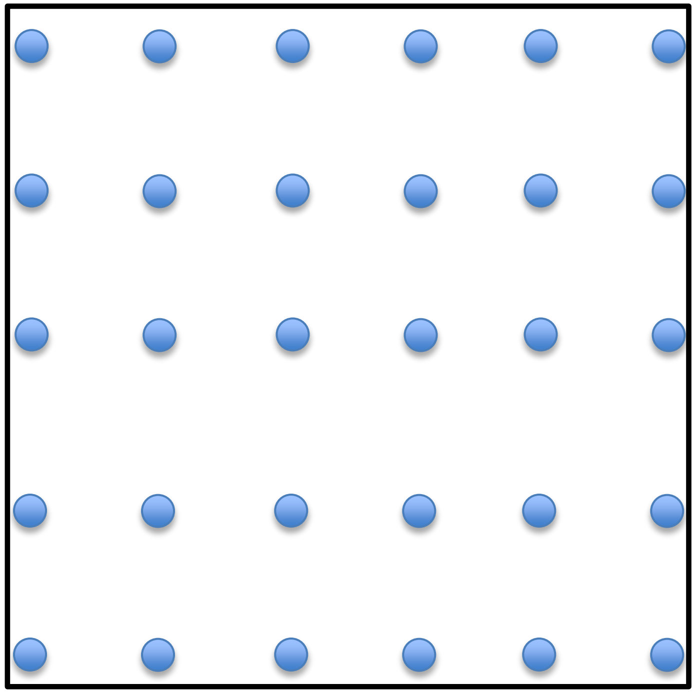
Parametric Analysis (rectangular Configuration)

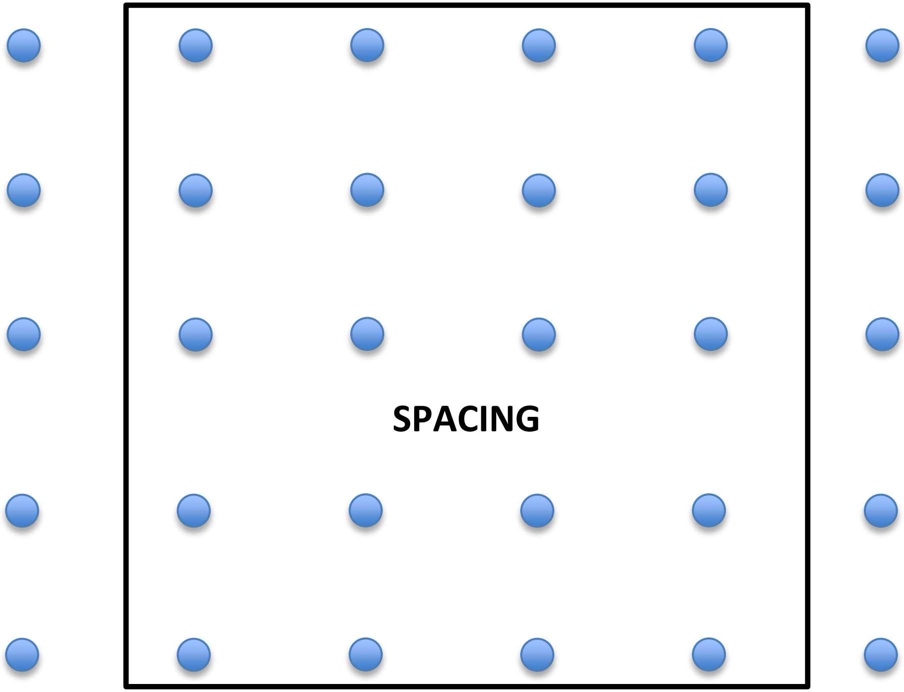


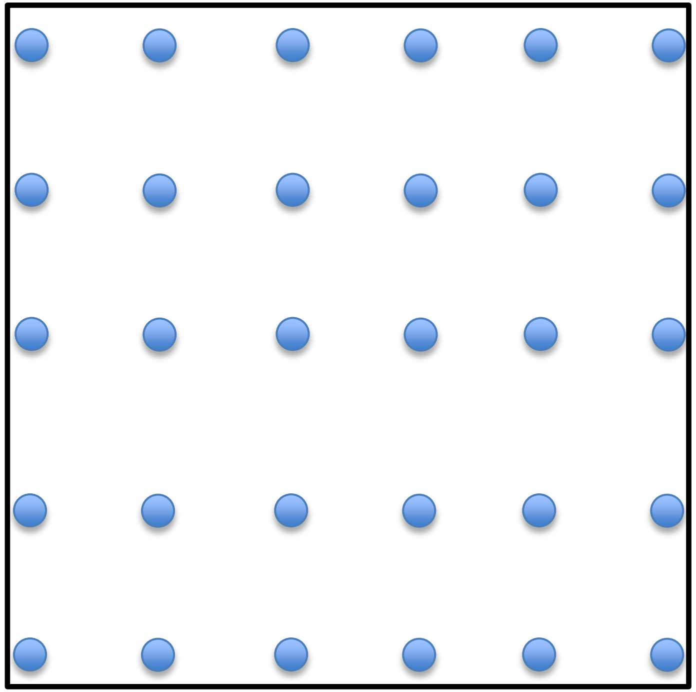
General Setup:

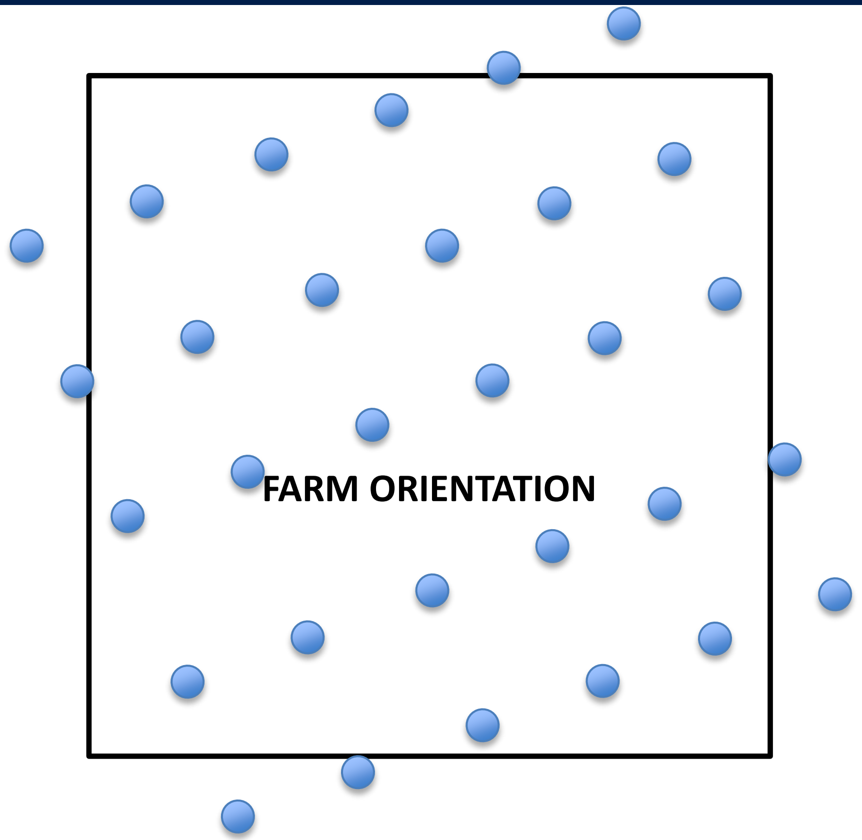
Line type: chain
Water depth: 1000m
Number of lines per turbine: 2
Umbilical sectional type: double armor - buoyancy

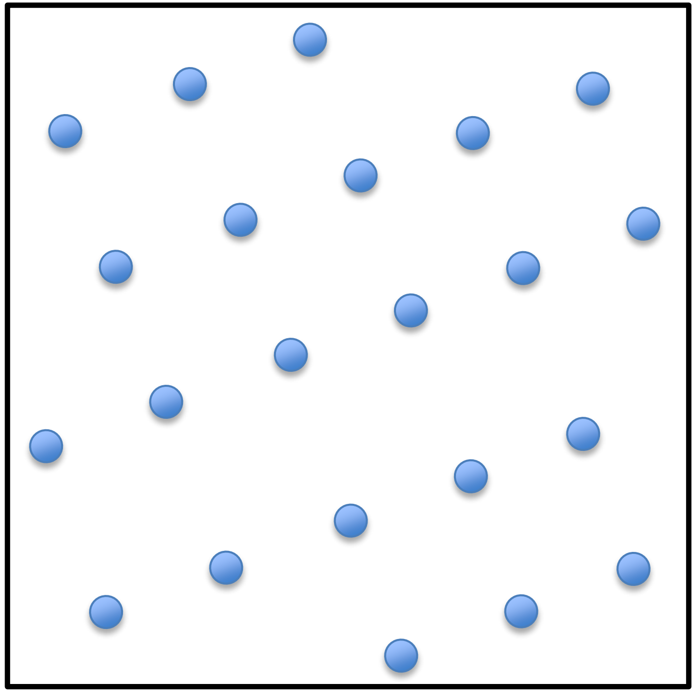




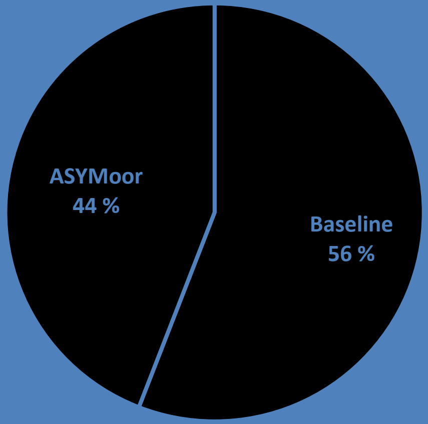

SPACING



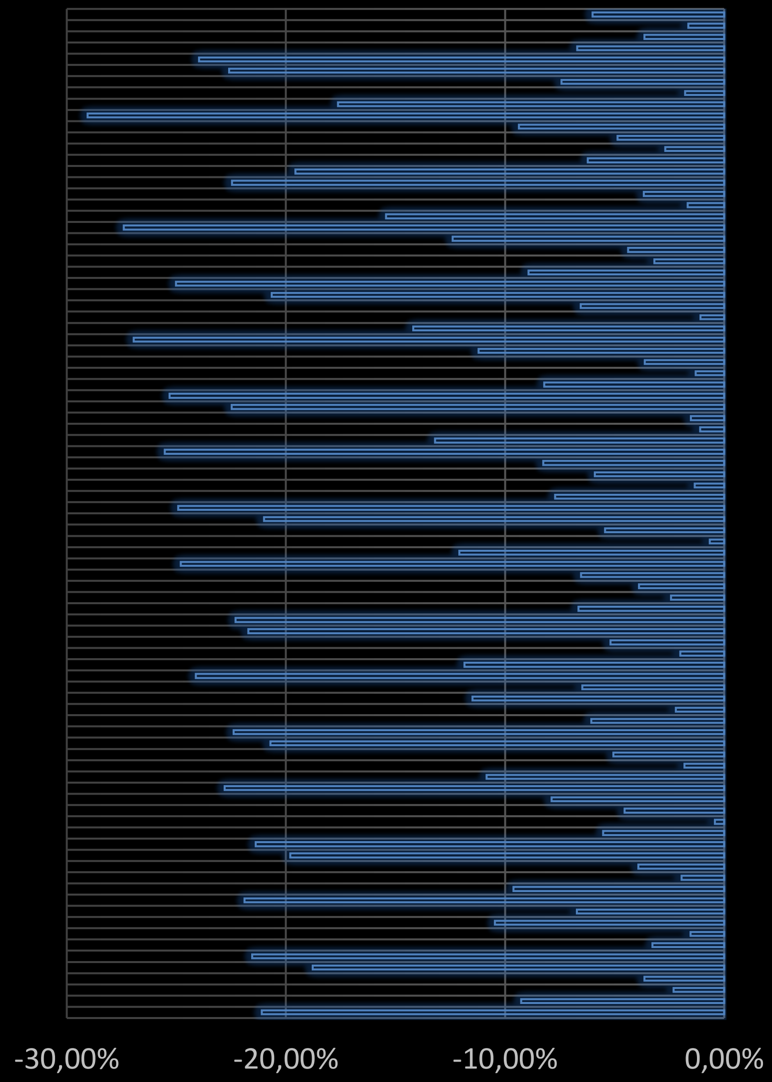

FARM ORIENTATION



WAKE LOSSES

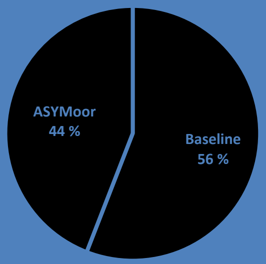


Wake effects reduction



AEY enhancement

WAKE LOSSES



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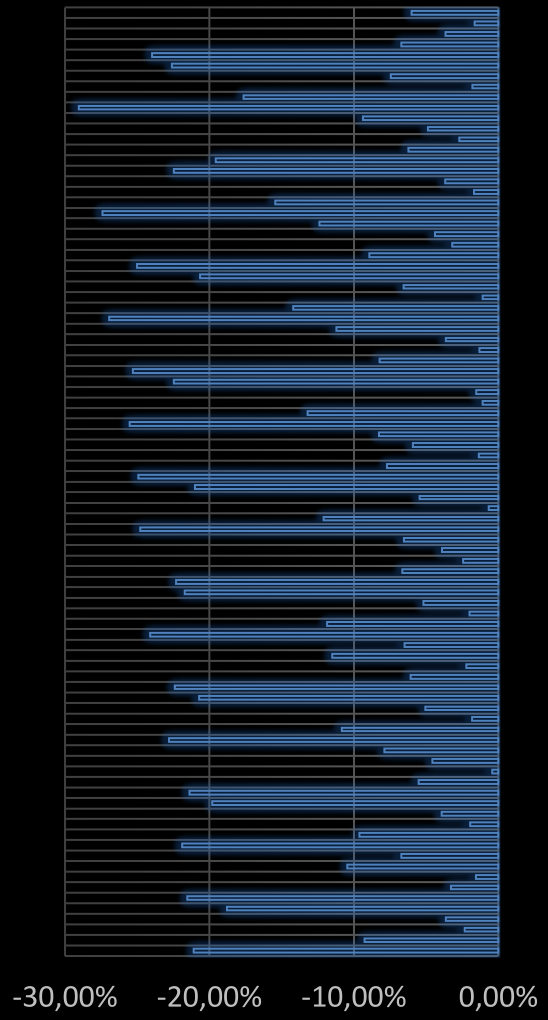

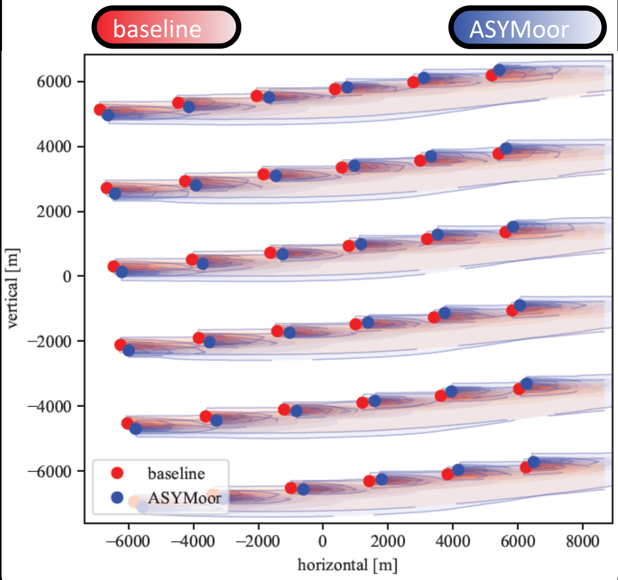

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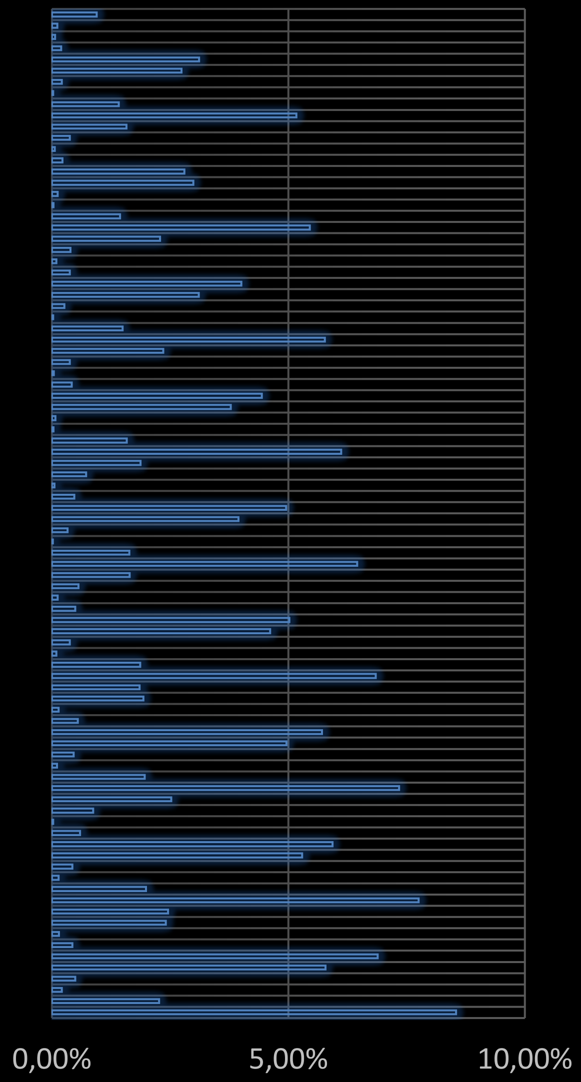

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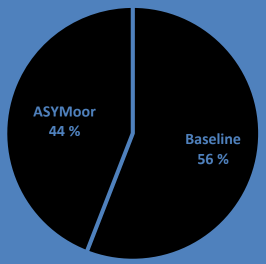

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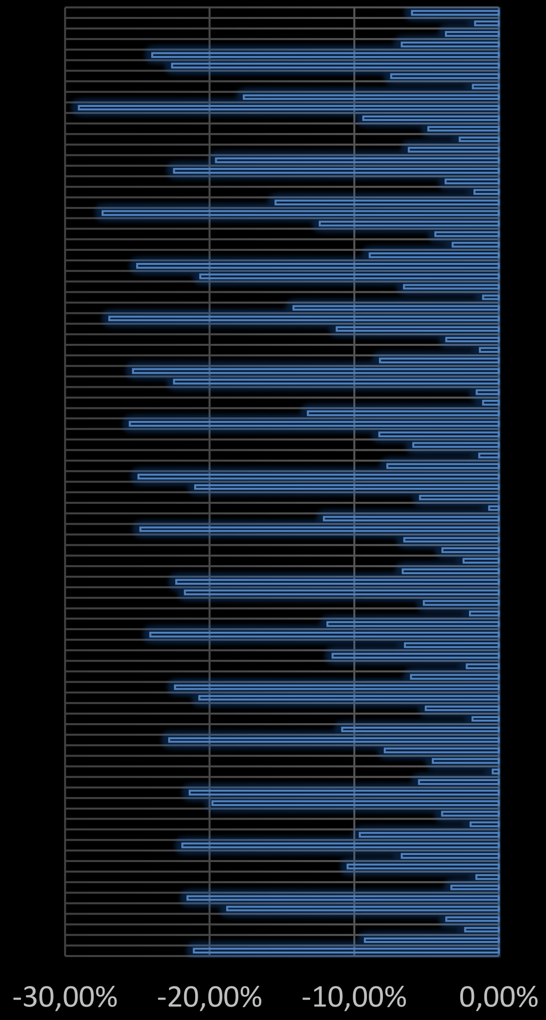

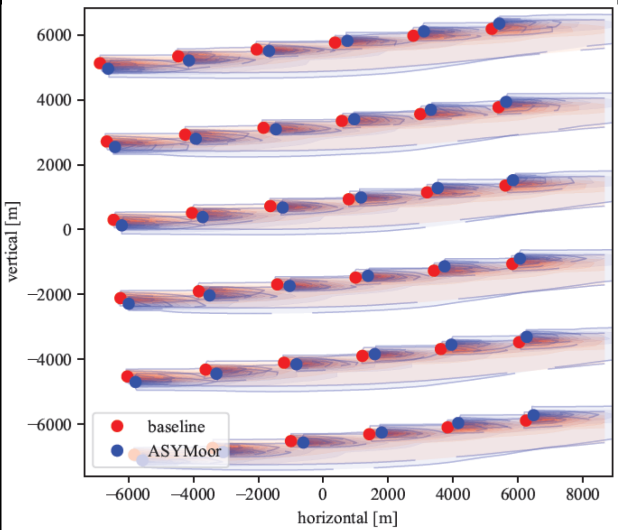

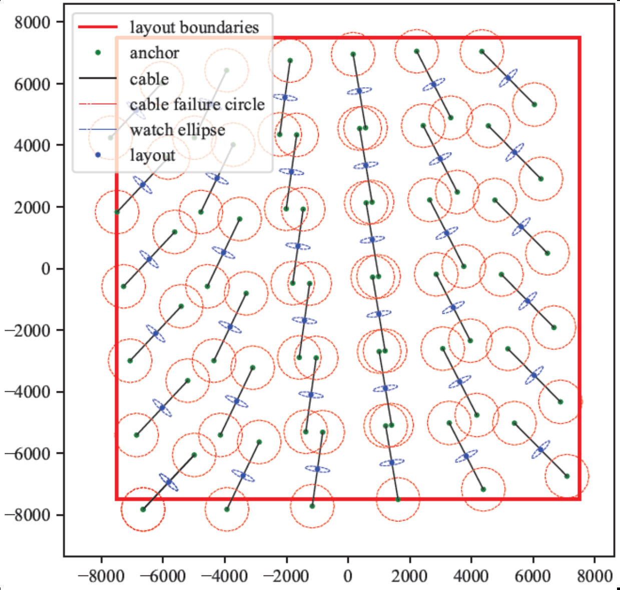

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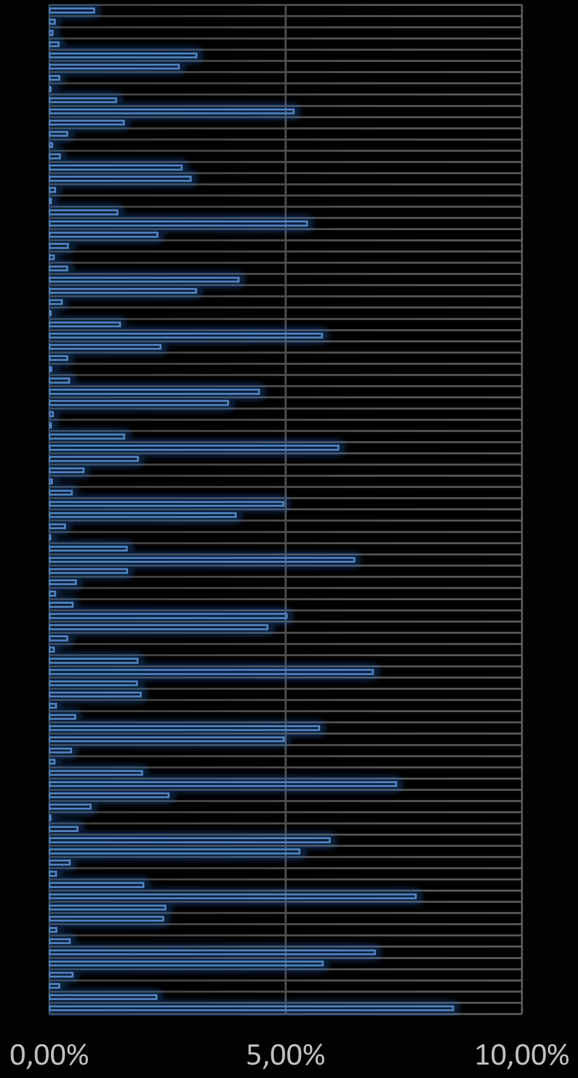
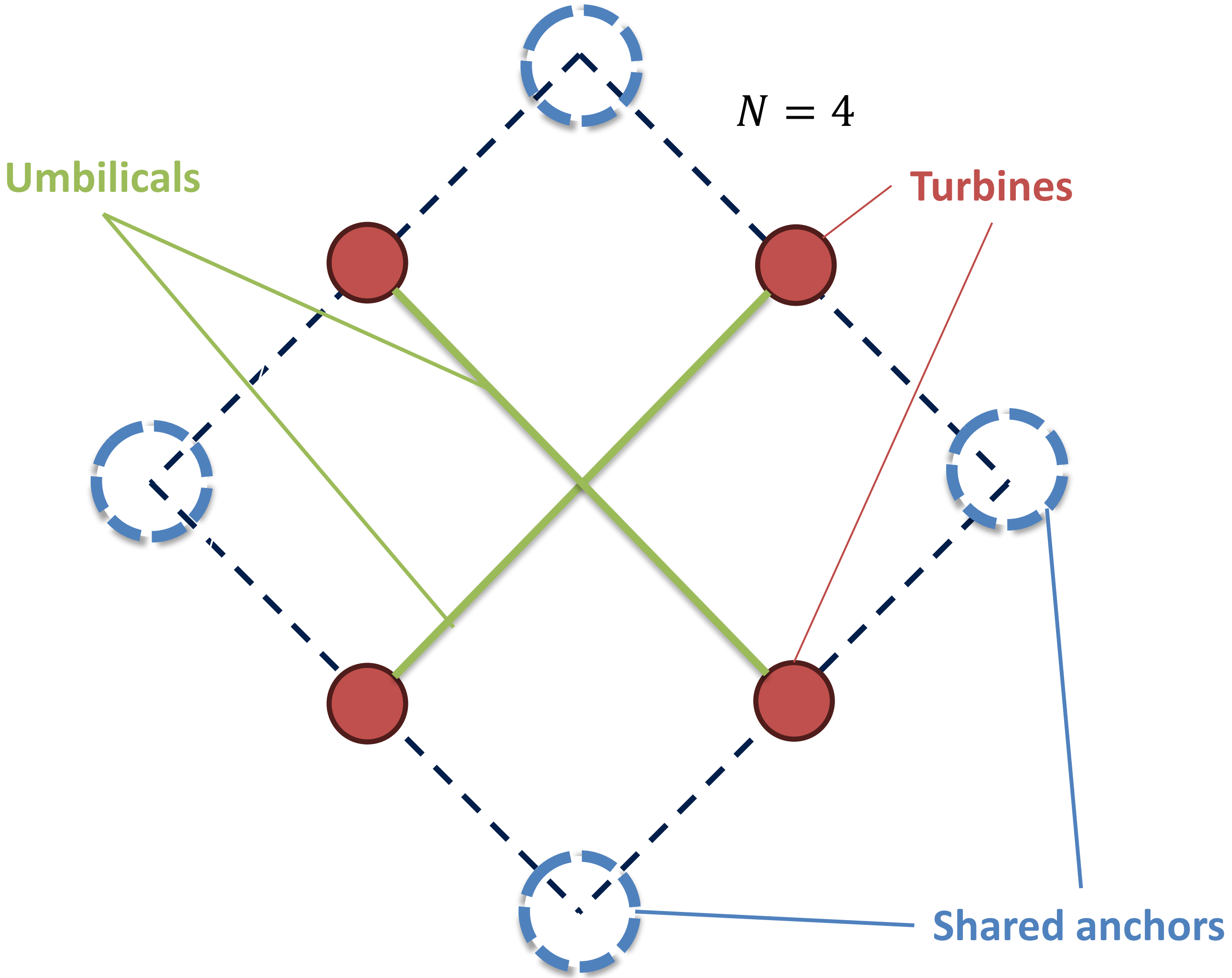


Turbine Clusters + Shared Anchors



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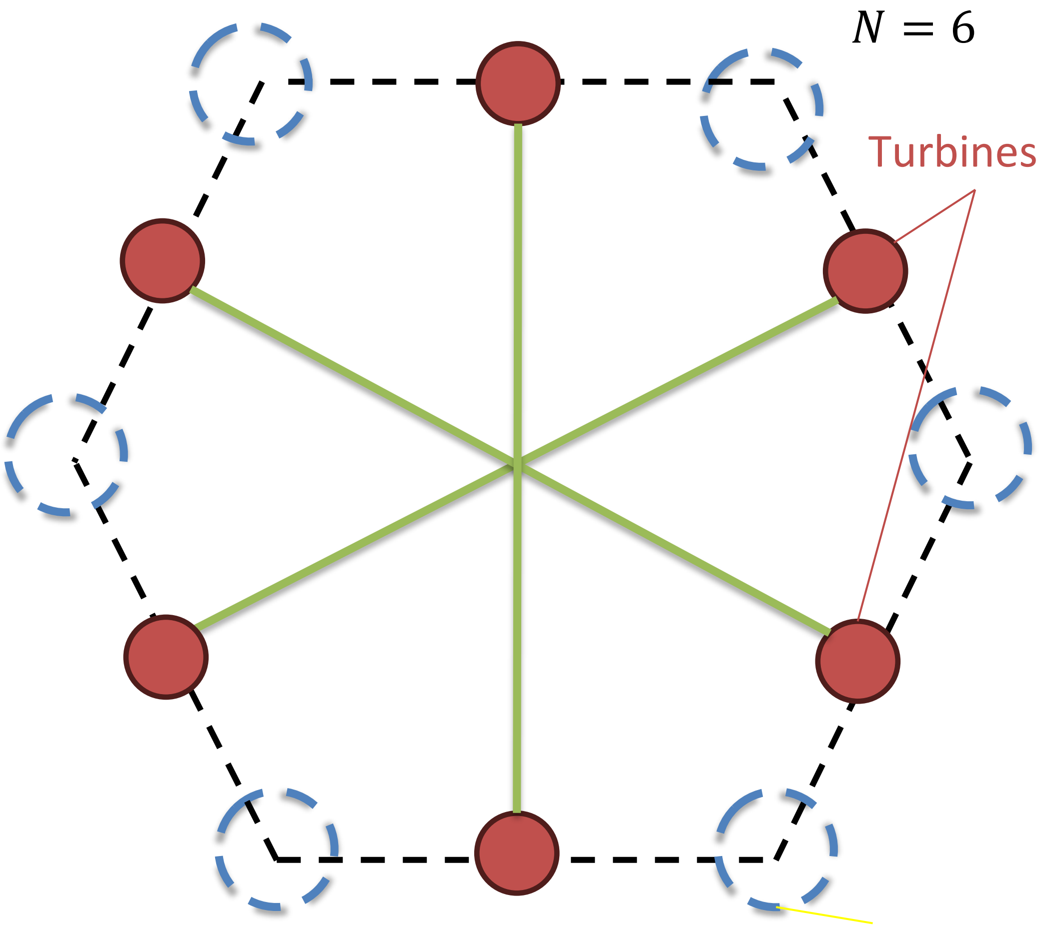

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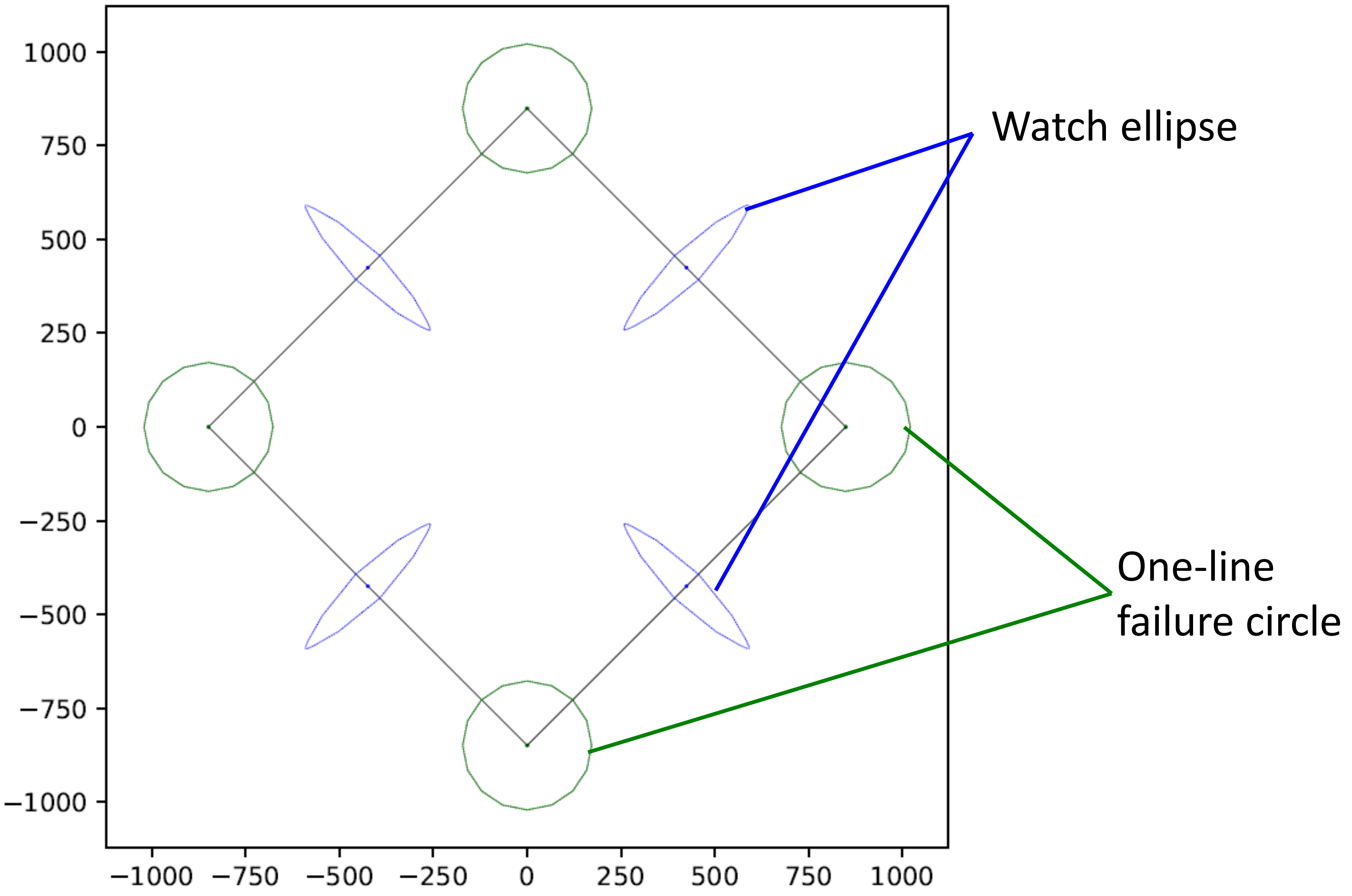

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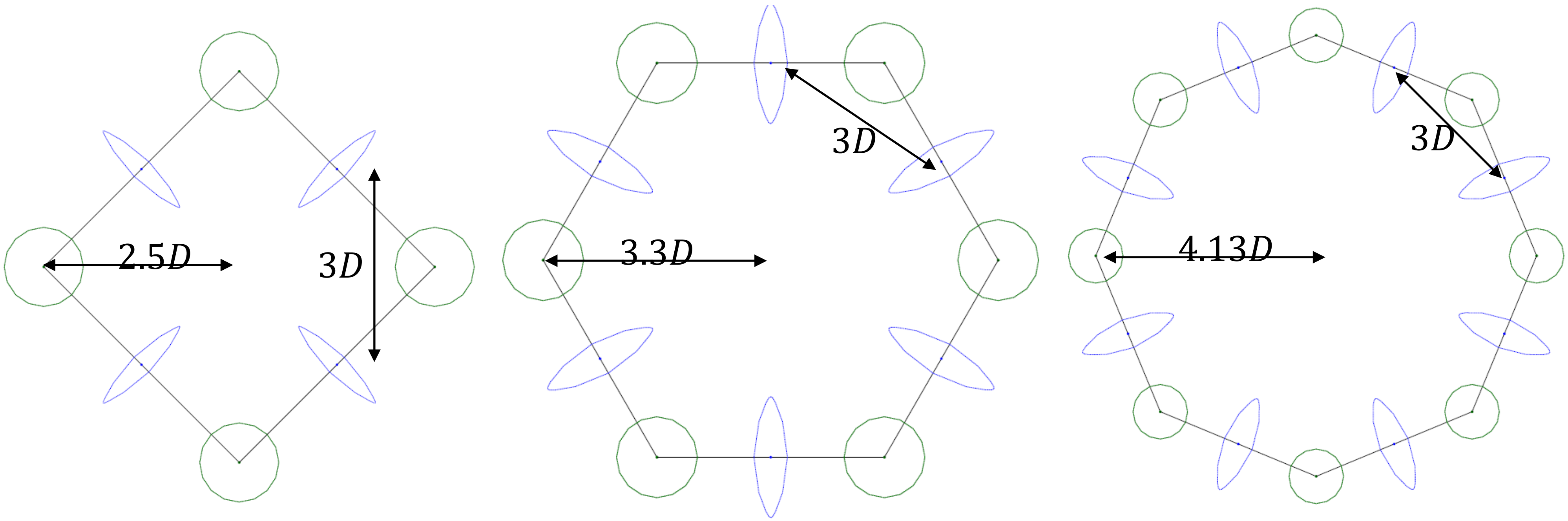

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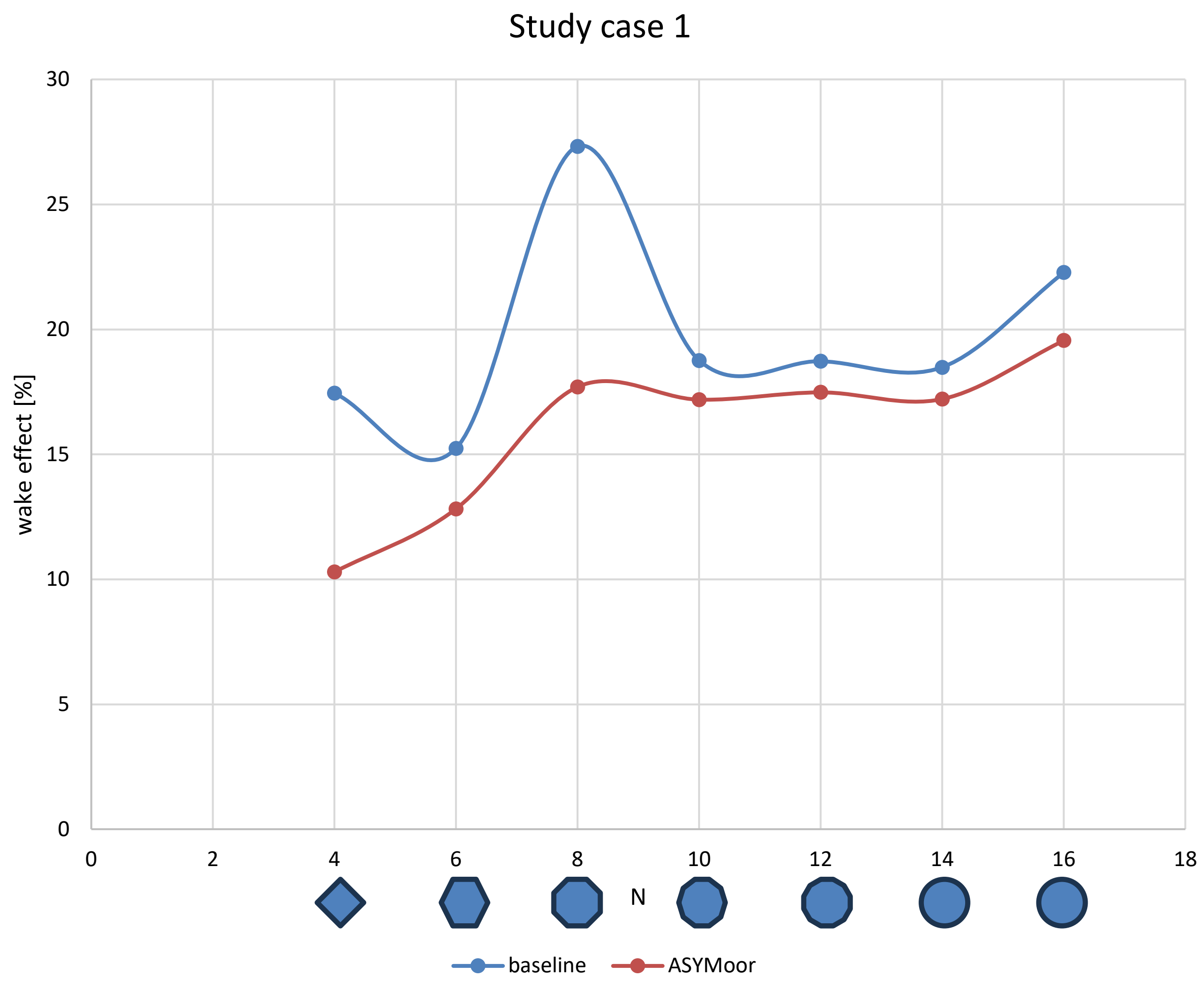

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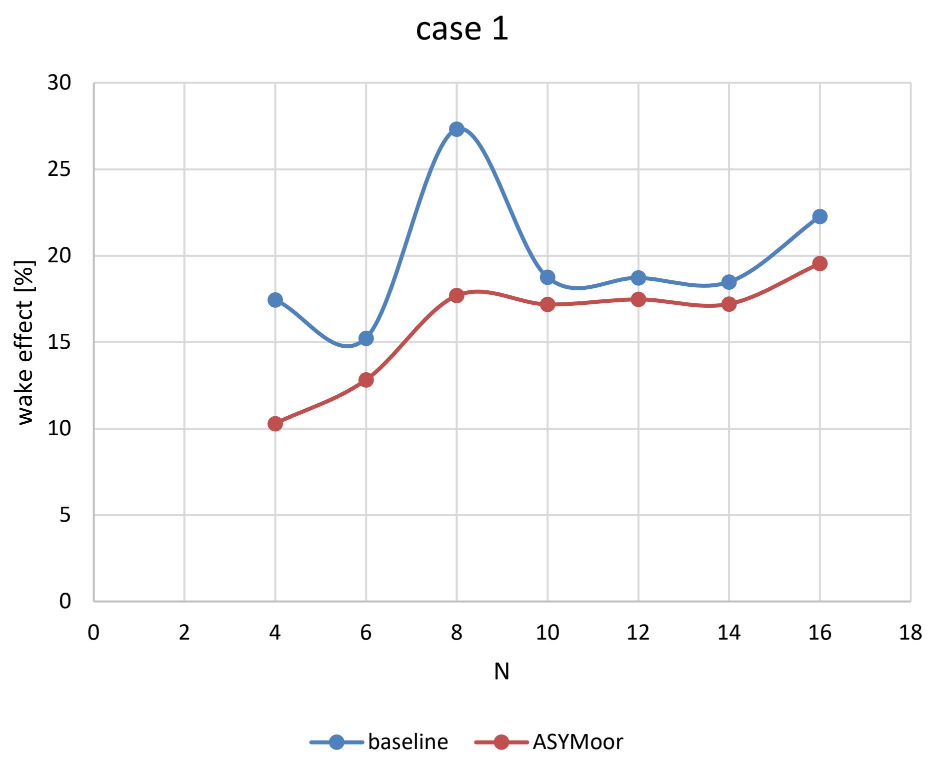
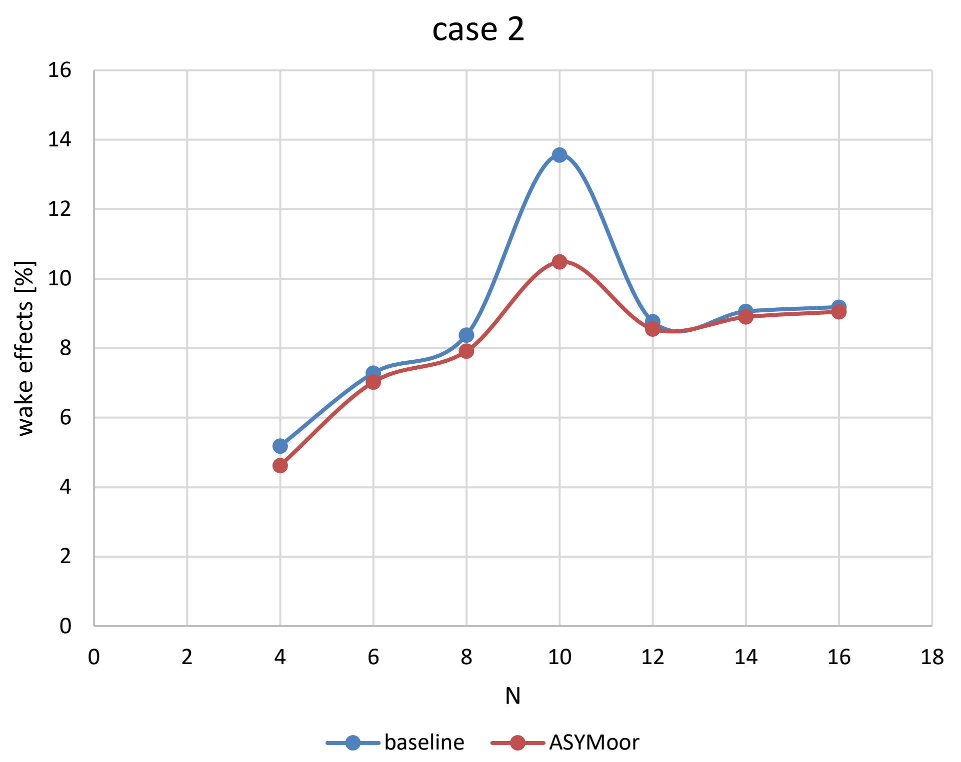
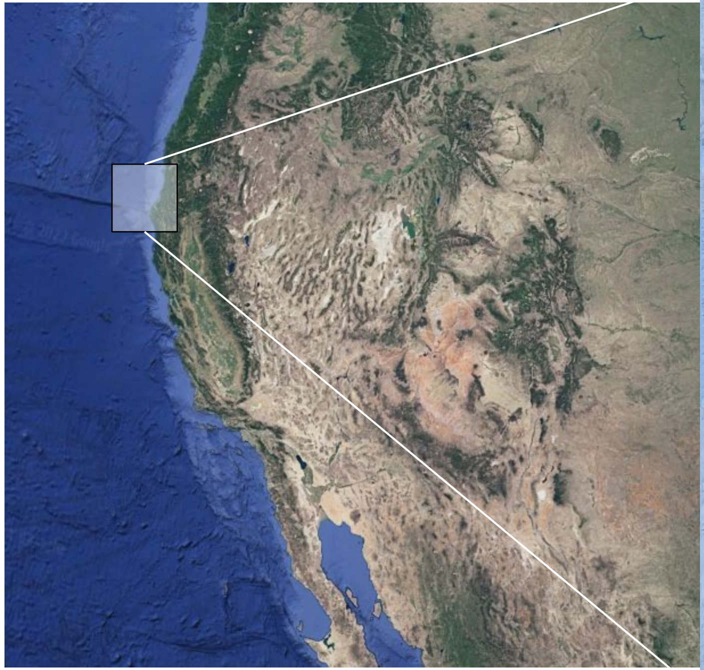
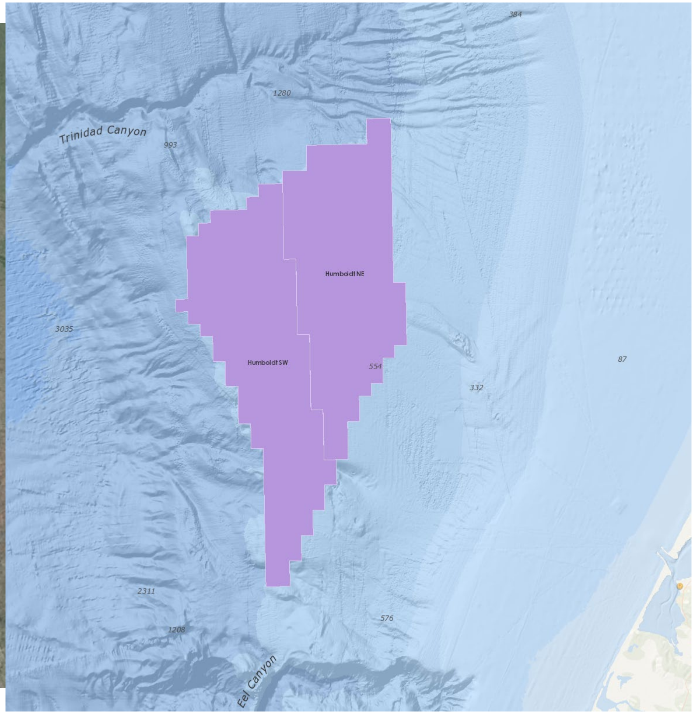


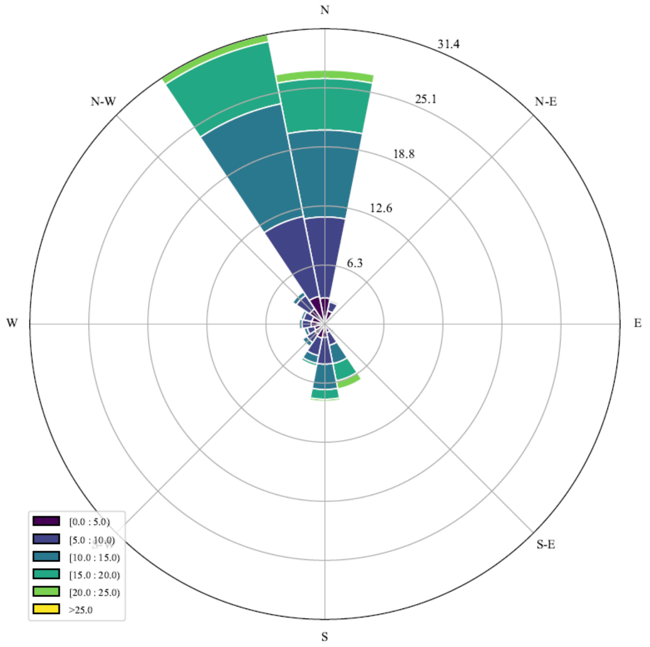


case 1:
Fixed rated wind speed varying wind direction
case 2:
Varying wind speed/wind direction

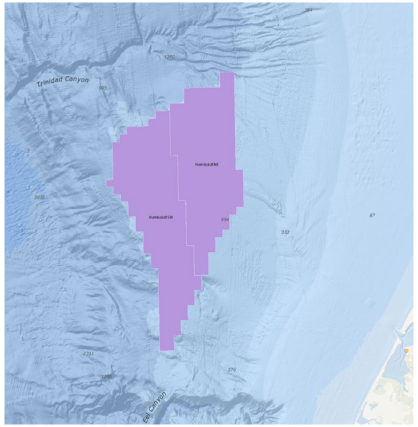
Humboldt Case Study

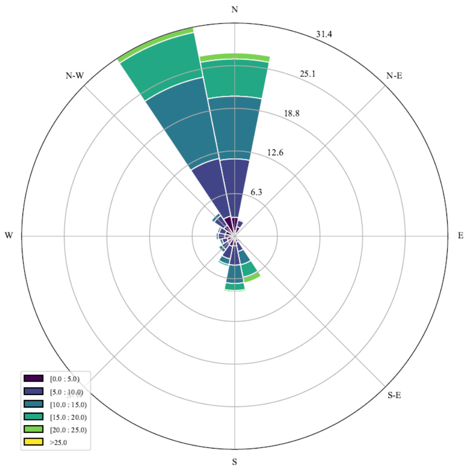






Humboldt Case Study

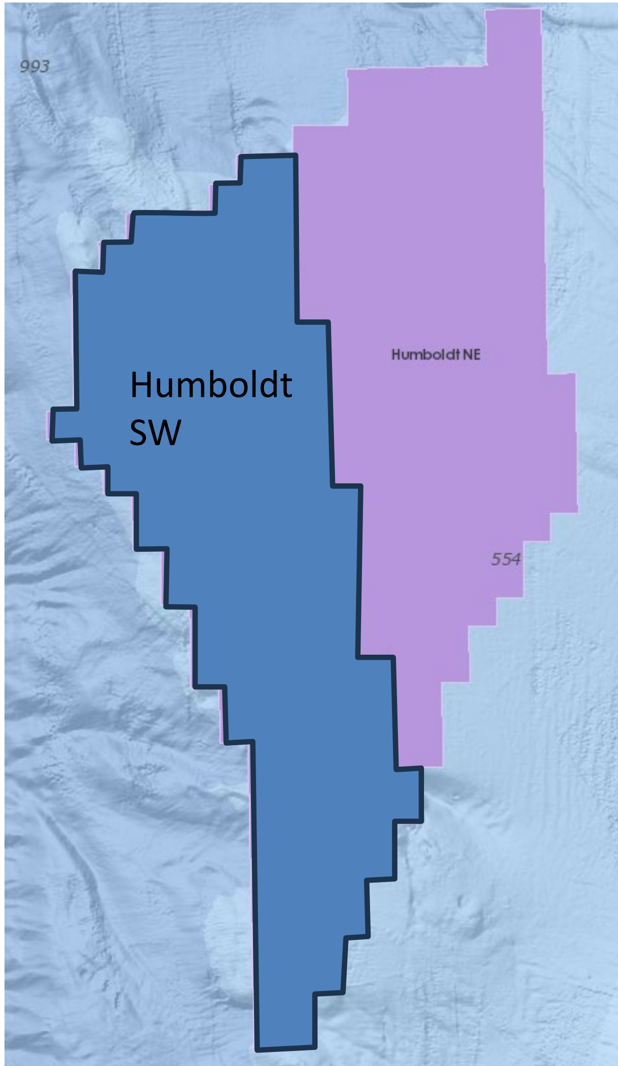




Parameter	NE Lease Area	SW Lease Area
Total area $[km^2]$	256	279
Average wind speed at 100m $[m/s]$	10.3	10.6
Average depth [m]	723	786
Depth range	537-1017	614-1137
Average distance from shore [km]	43	47
Capacity [MW]	1000	1600

Wind data for 20+ yrs extracted from Climate Data Store (CDS) database

Humboldt – Turbine Clusters Optimization Problem



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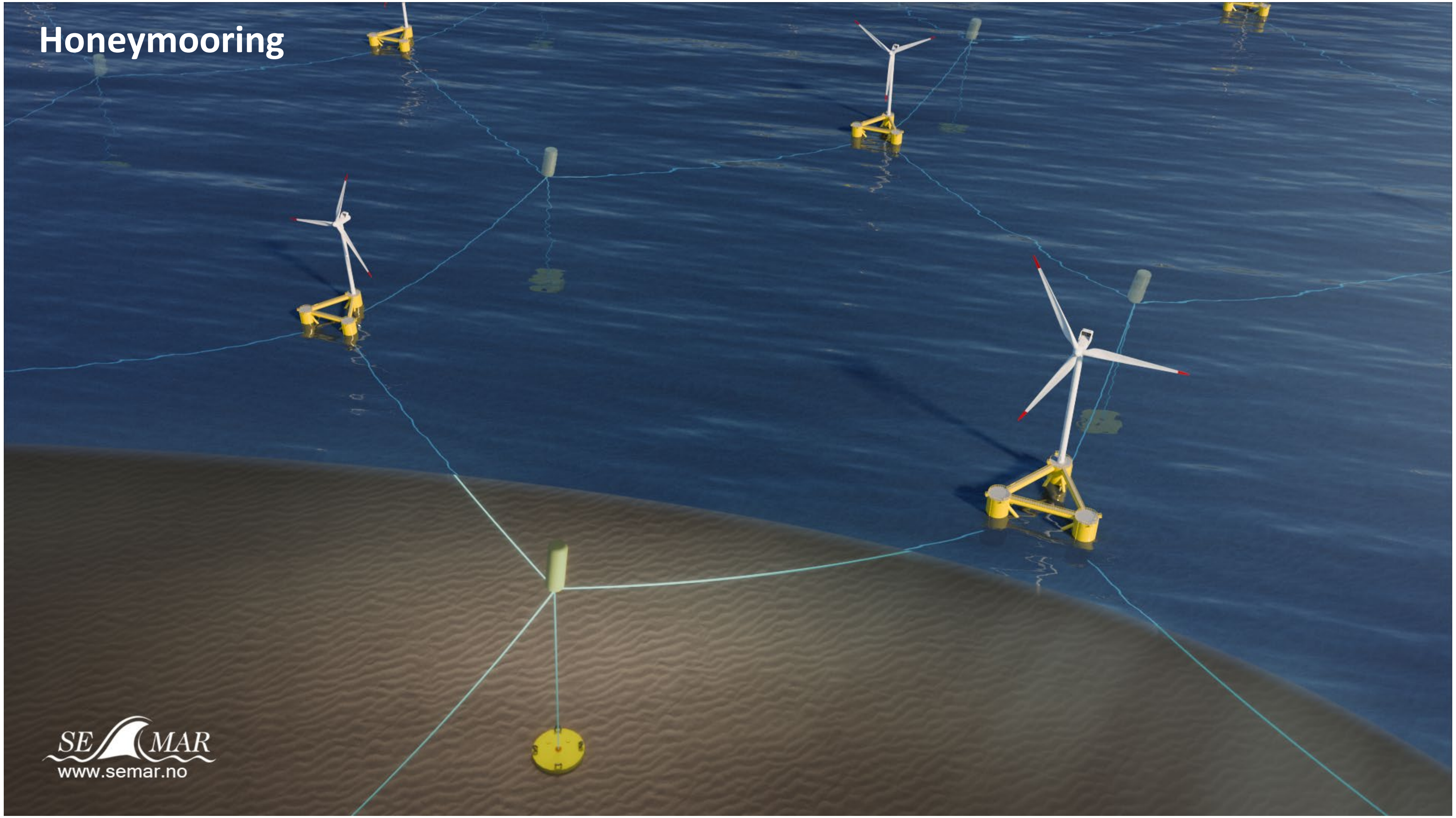


Humboldt – Turbine Clusters Optimization Problem

Candidates

Baseline case (3-mooring configuration)

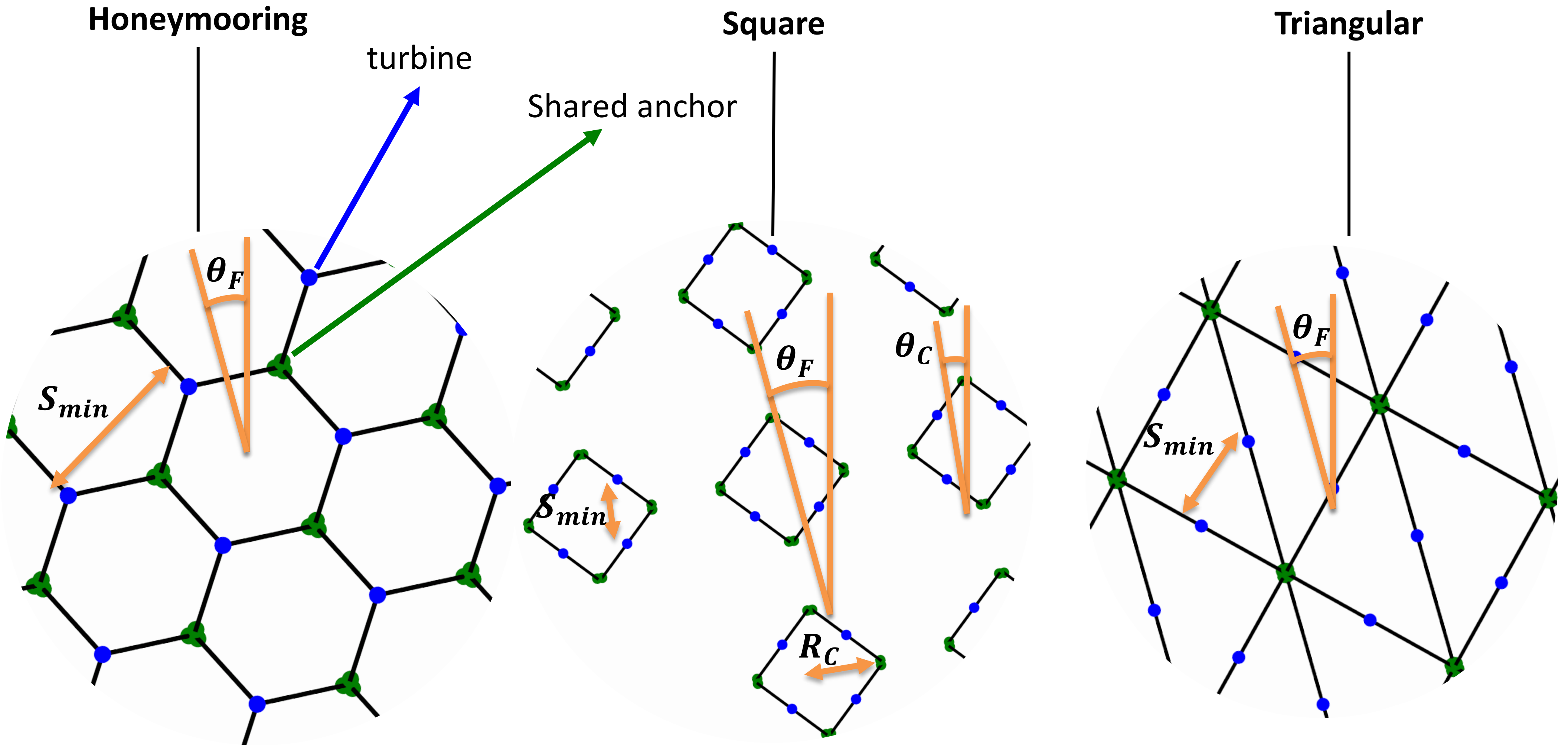
Honeymooring

ASYMoor (2-mooring configuration)

Square

Triangular

Humboldt – Turbine Clusters Optimization Problem

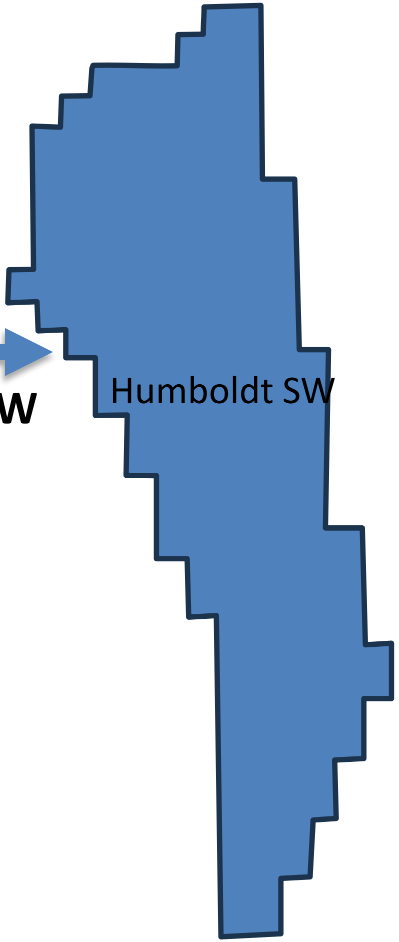


Humboldt – Turbine Clusters Optimization Problem

Candidates

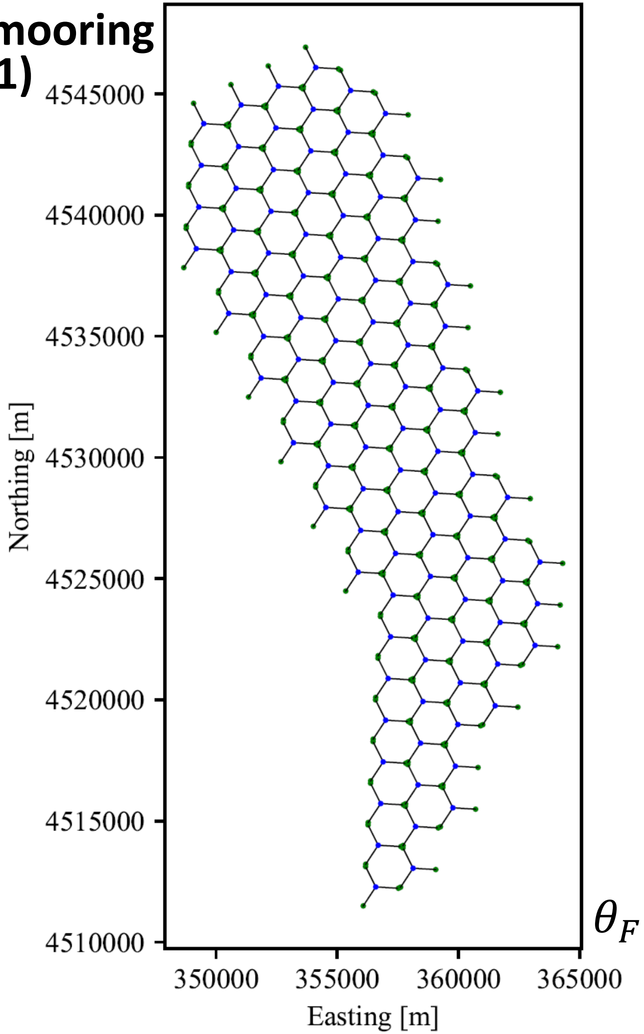
Honeymooring (1) θ_F	**Square (1)** θ_c, R_L, θ_F	**Triangular (1)** θ_F
Honeymooring (2) θ_F, S_{min}	**Square (2)** $\theta_c, R_L, \theta_F, S_{min}$	**Triangular (2)** θ_F, S_{min}

Capacity = 1600MW



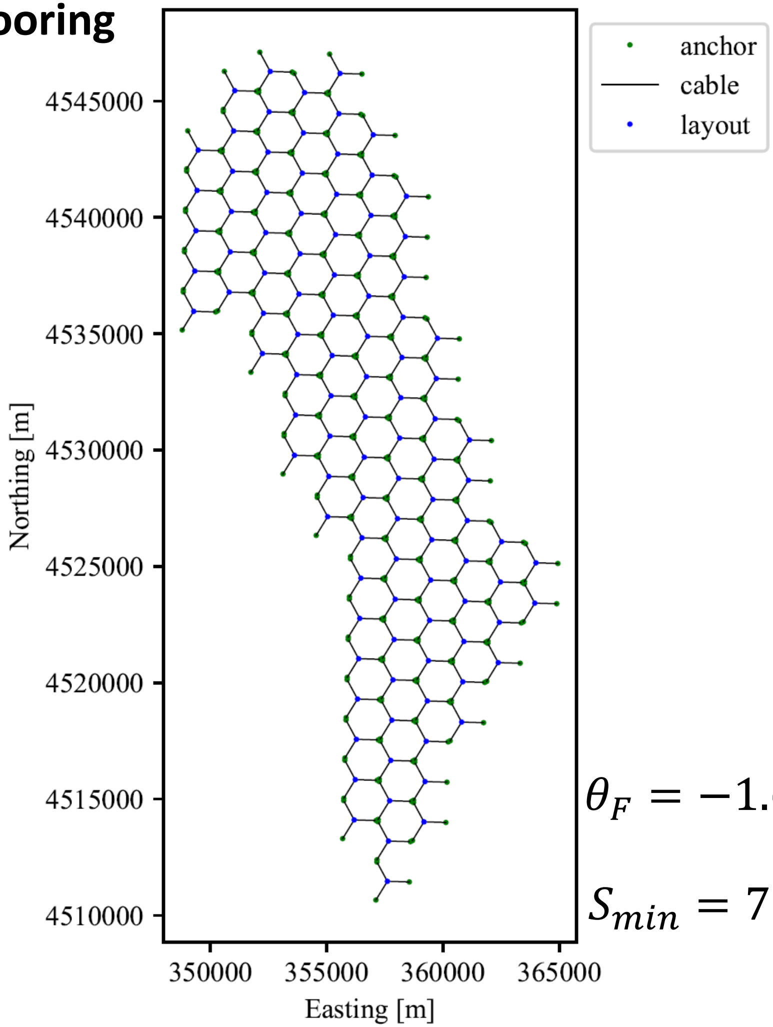
Humboldt – Turbine Clusters Optimization Problem

Honeymooring (1)



$\theta_F = -3.40°$

Honeymooring (2)

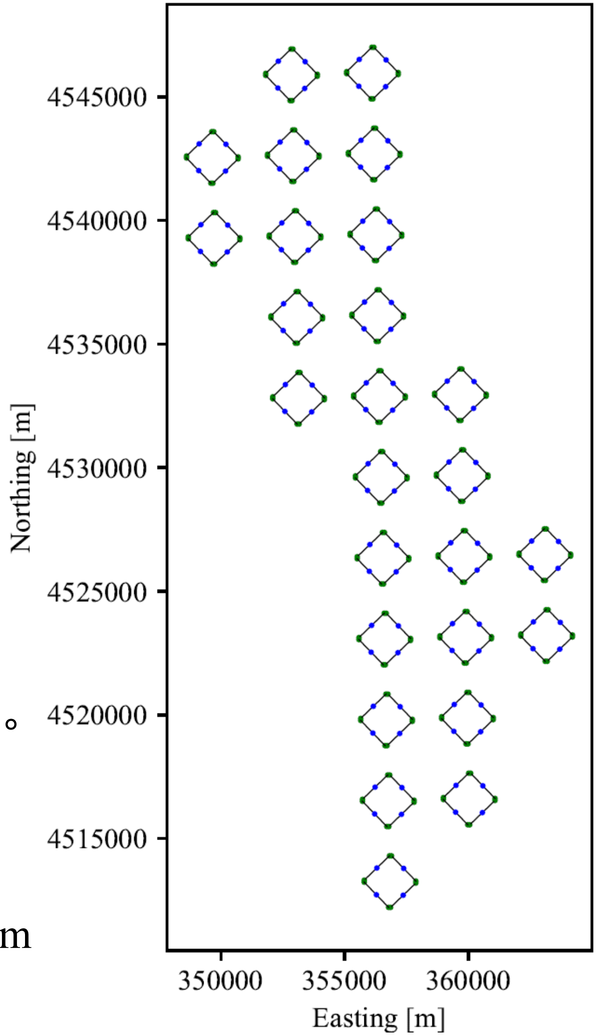


$\theta_F = -1.60°$

$S_{min} = 7.15D$

Humboldt – Turbine Clusters Optimization Problem

Square (1)

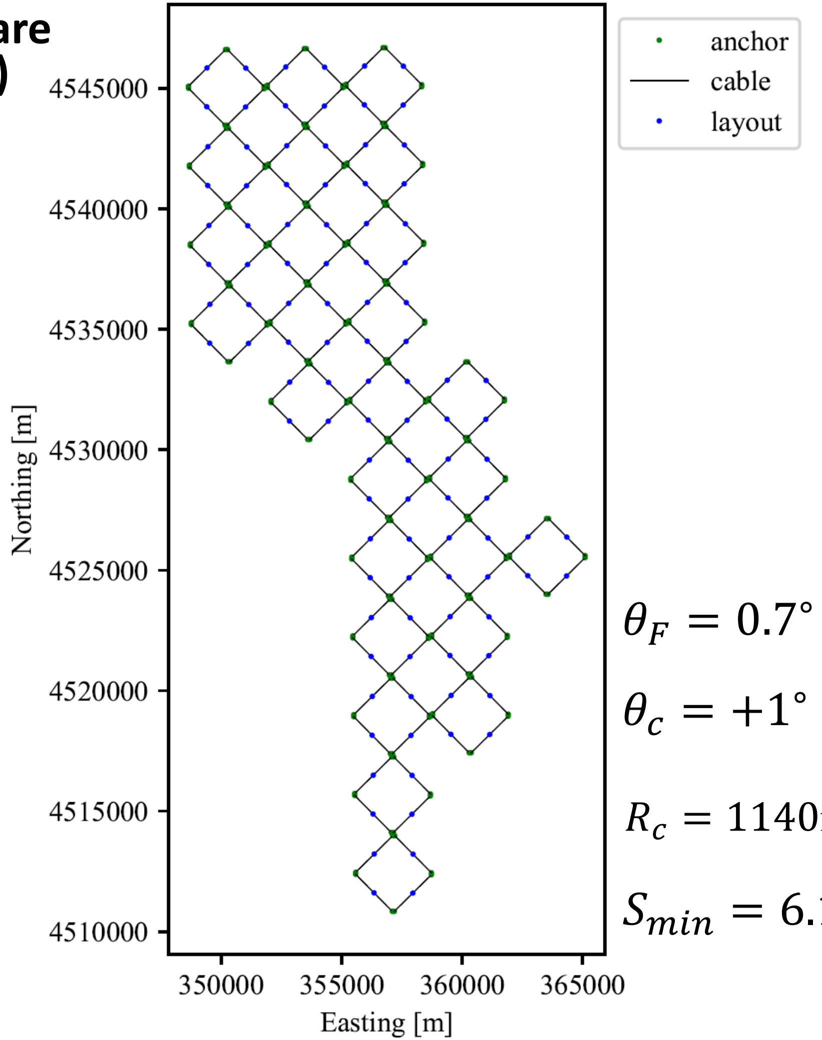


$\theta_F = 1.25°$

$\theta_c = -1°$

$R_c = 766.23\text{m}$

Square (2)



$\theta_F = 0.7°$

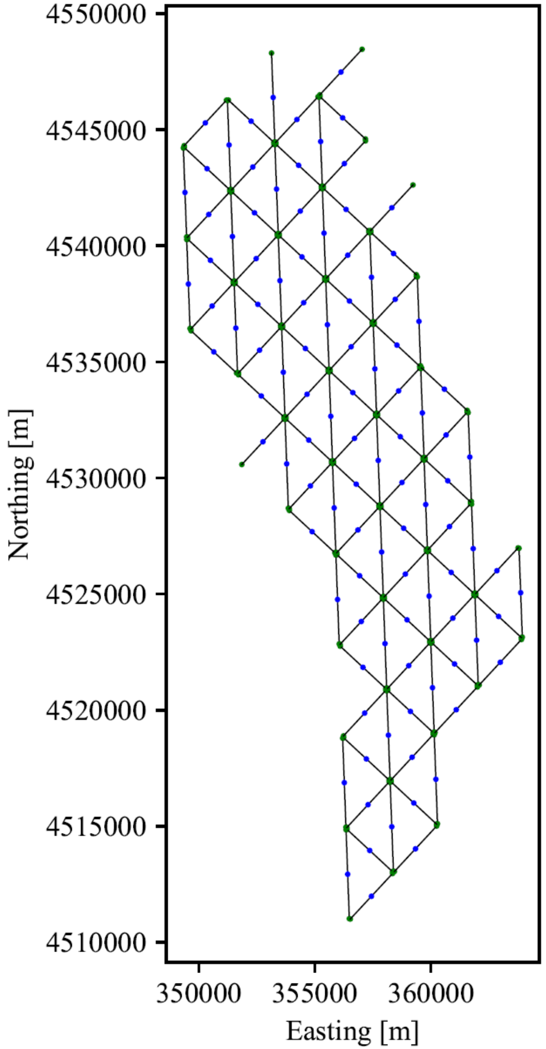
$\theta_c = +1°$

$R_c = 1140\text{m}$

$S_{min} = 6.16D$

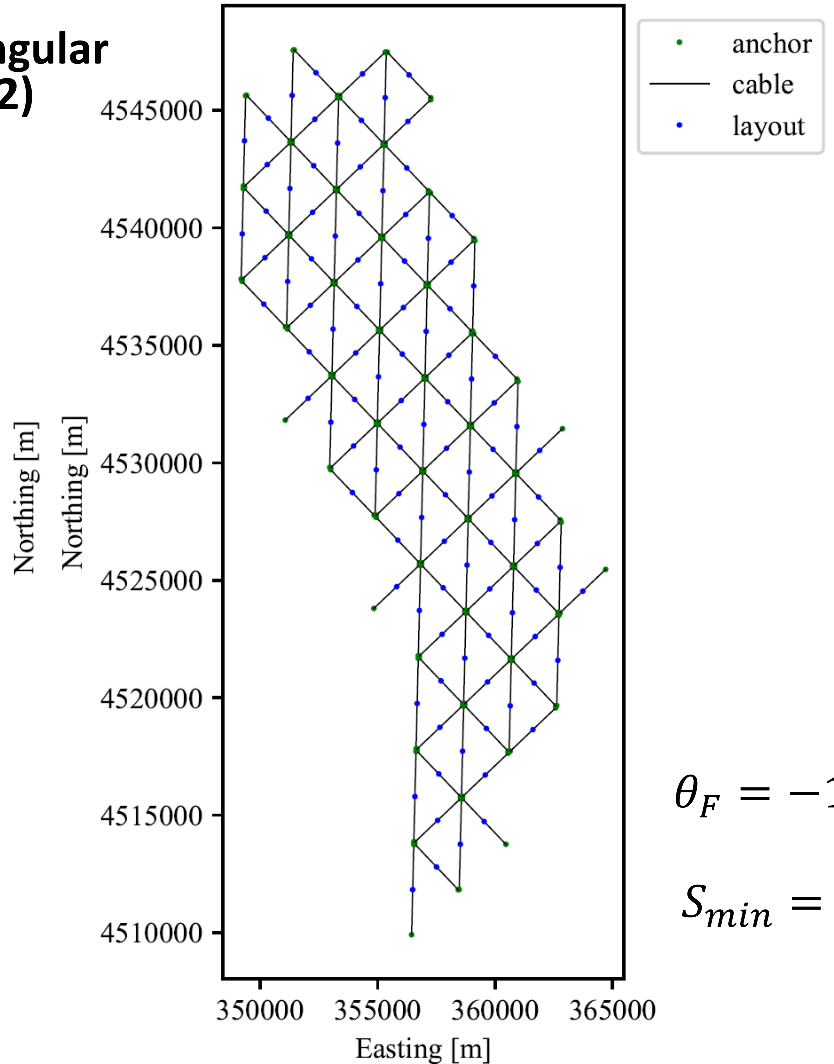
Humboldt – Turbine Clusters Optimization Problem

Triangular (1)



$\theta_F = 2.11°$

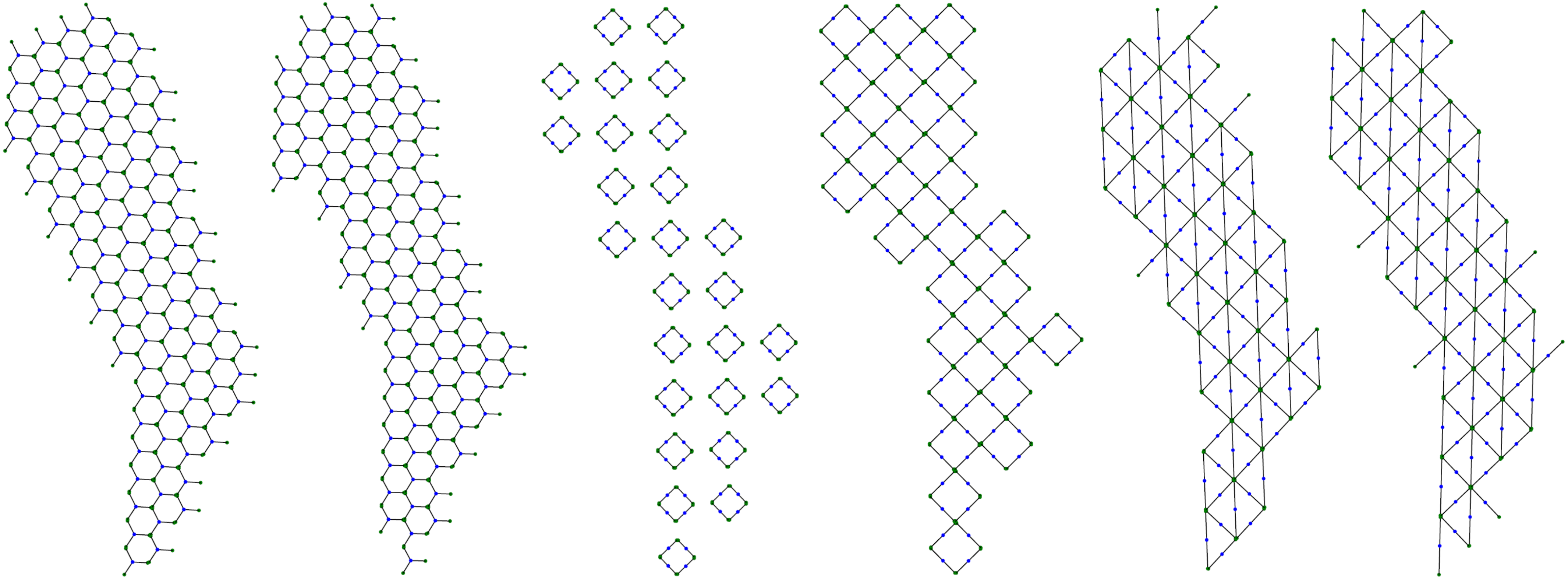
Triangular (2)



$\theta_F = -1.38°$

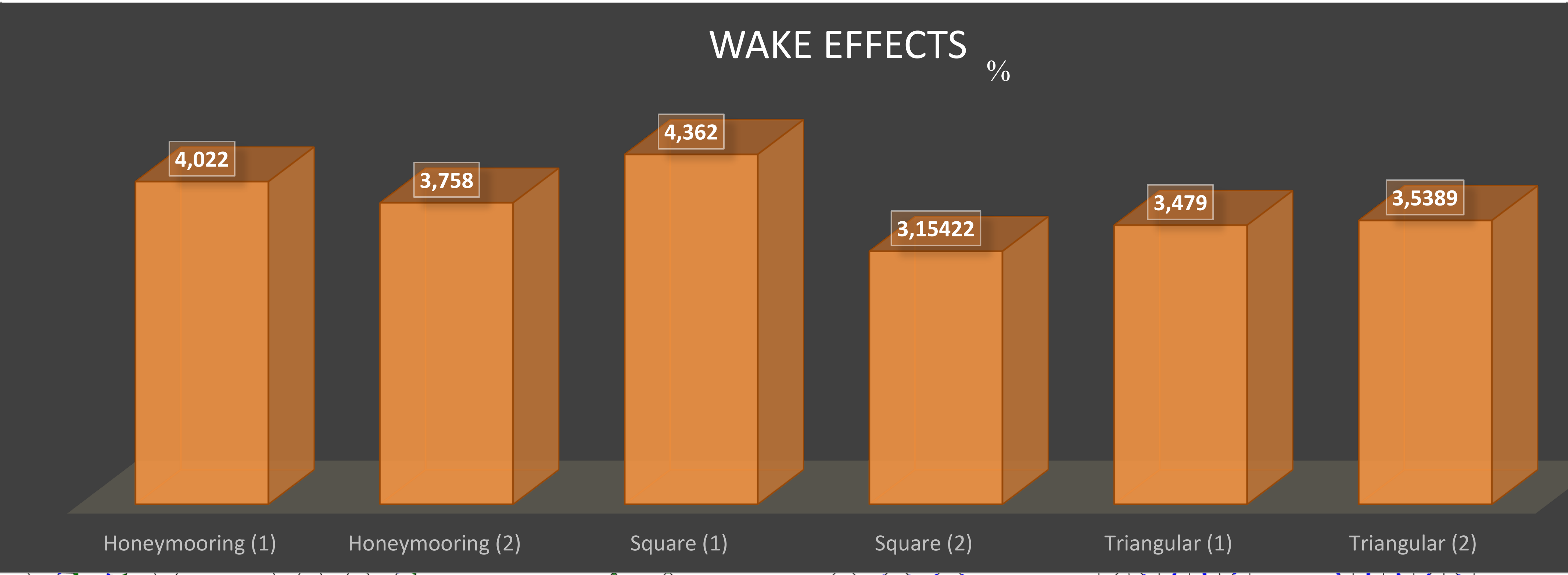
$S_{min} = 5.78D$

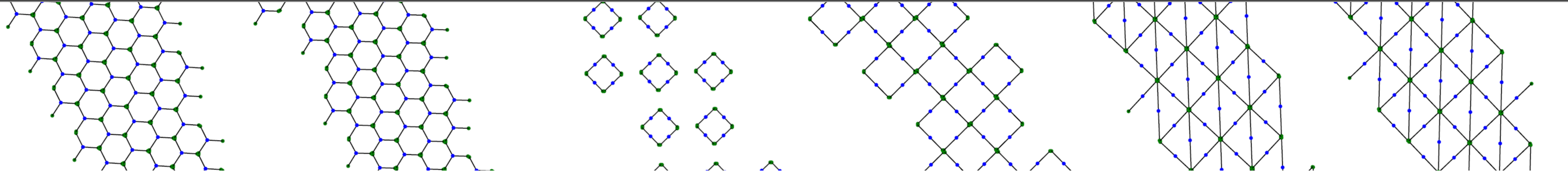
Humboldt – Turbine Clusters Optimization Problem



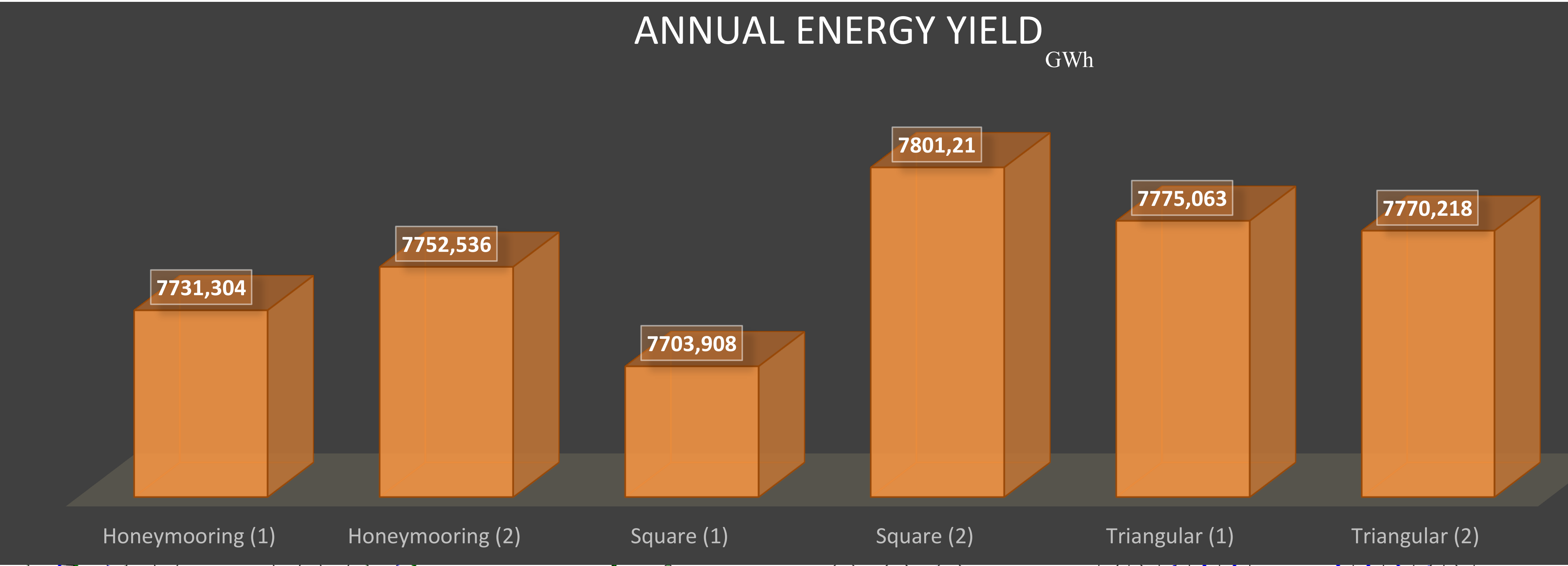
HM1 HM2 SQ1 SQ2 TR1 TR2

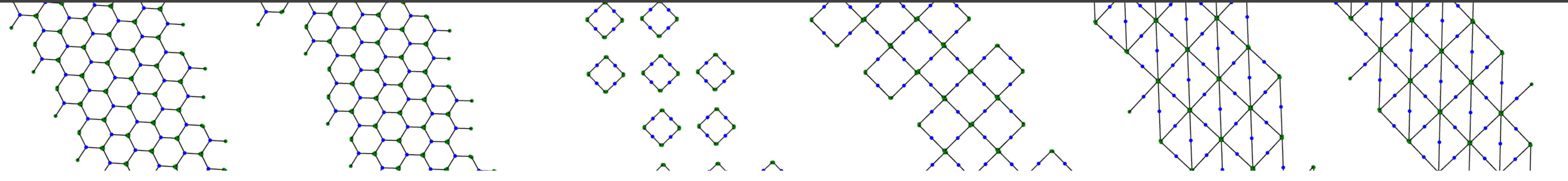
Humboldt – Turbine Clusters Optimization Problem



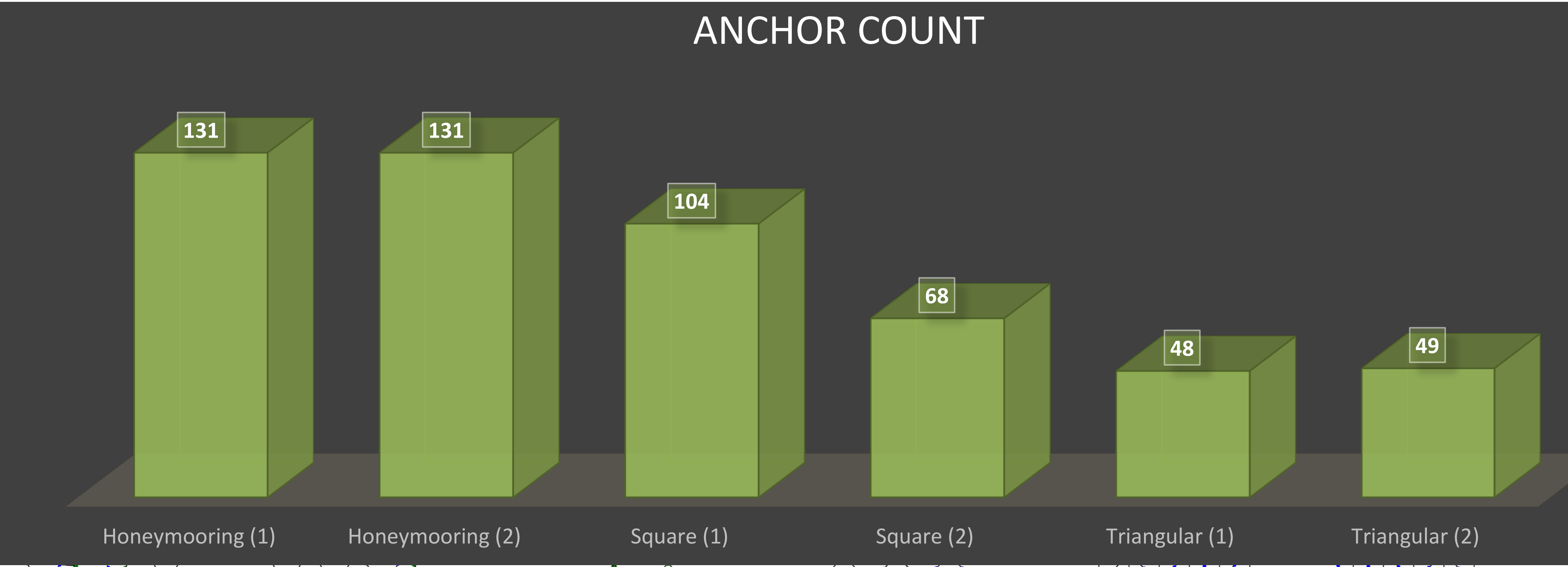


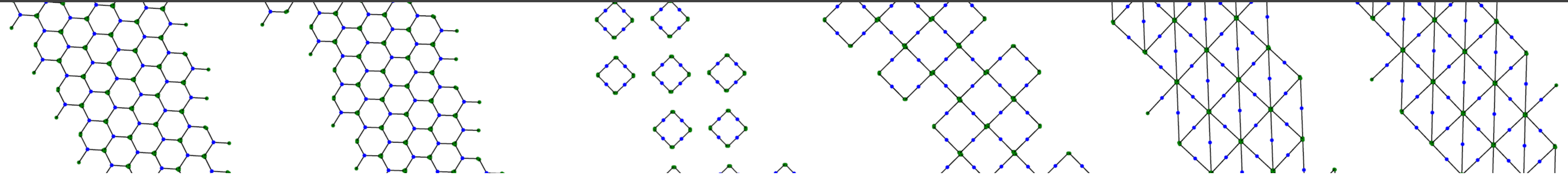
Humboldt – Turbine Clusters Optimization Problem



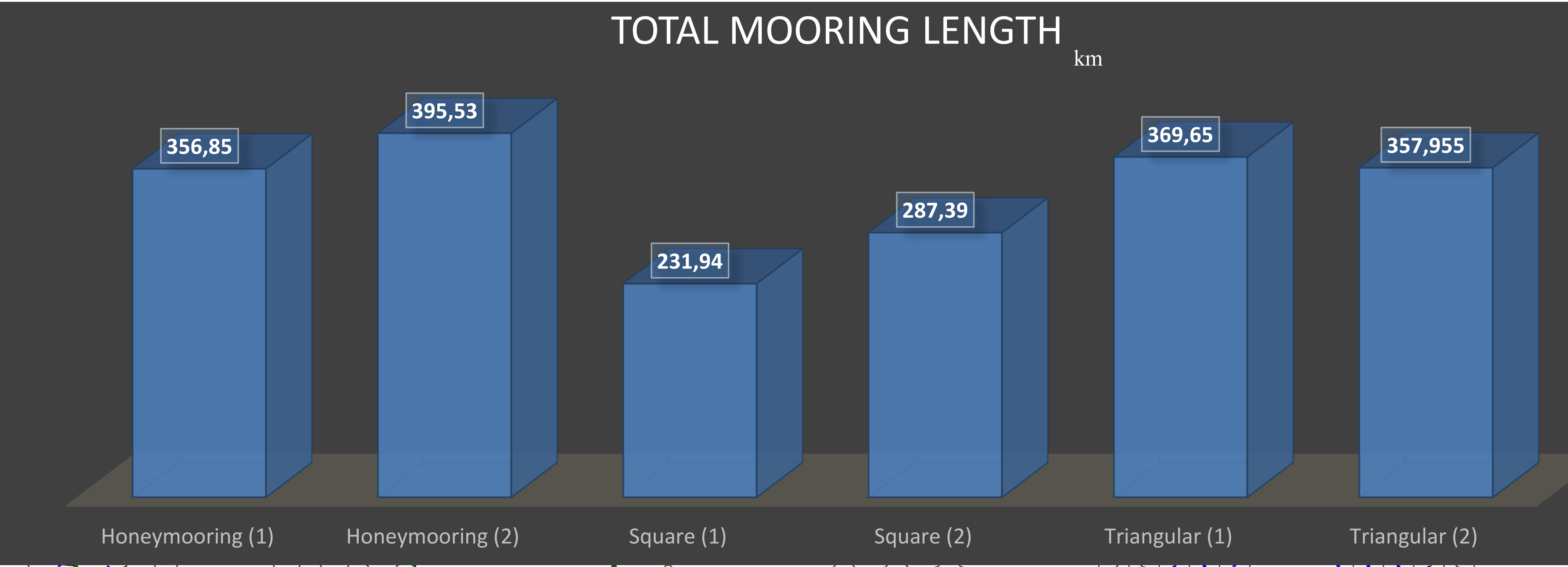


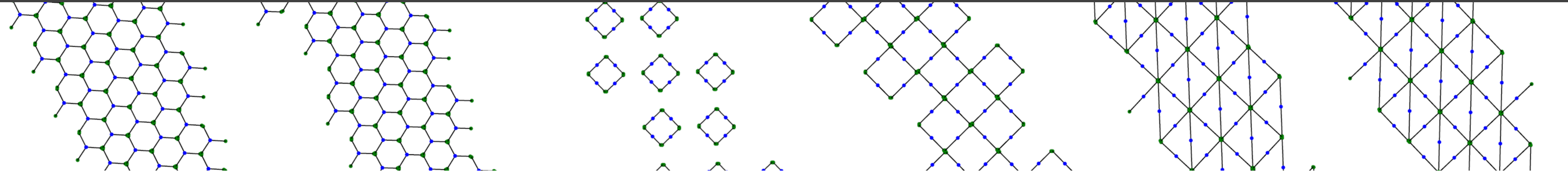
Humboldt – Turbine Clusters Optimization Problem

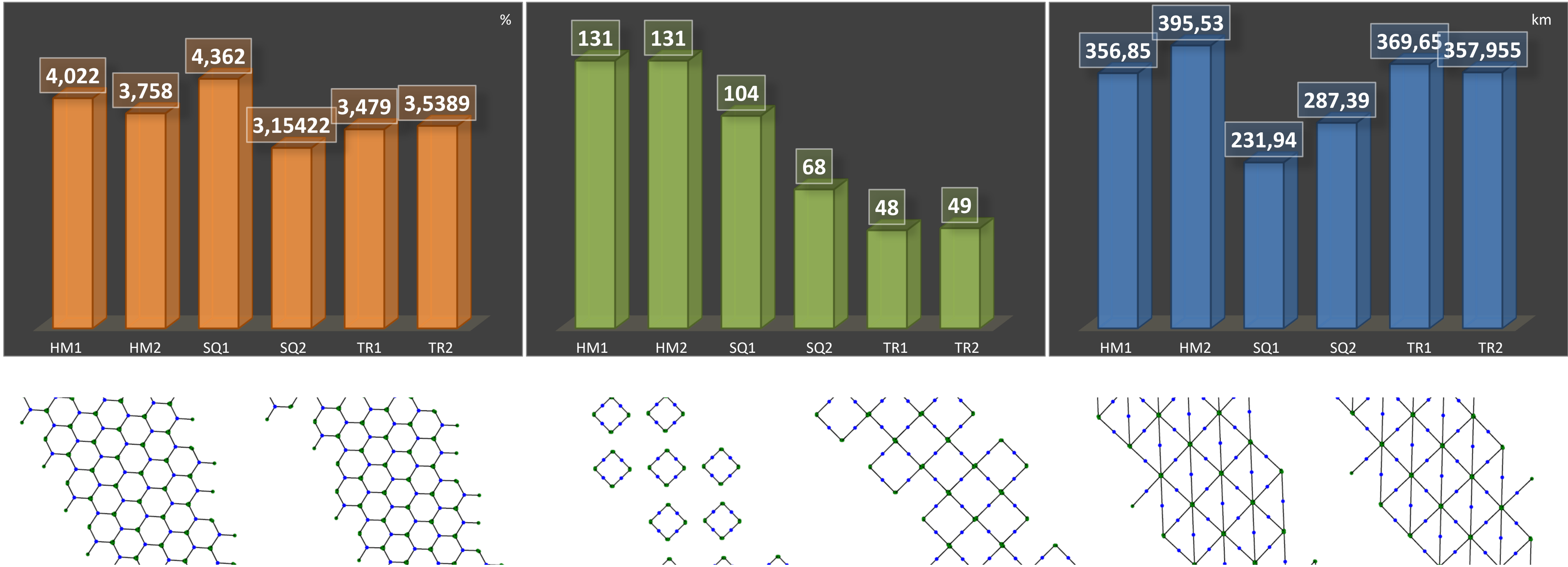




Humboldt – Turbine Clusters Optimization Problem



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3,758
4,362
3,15422
3,479
3,5389
HM1
HM2
SQ1
SQ2
TR1
TR2
131
131
104
68
48
49
HM1
HM2
SQ1
SQ2
TR1
TR2
km
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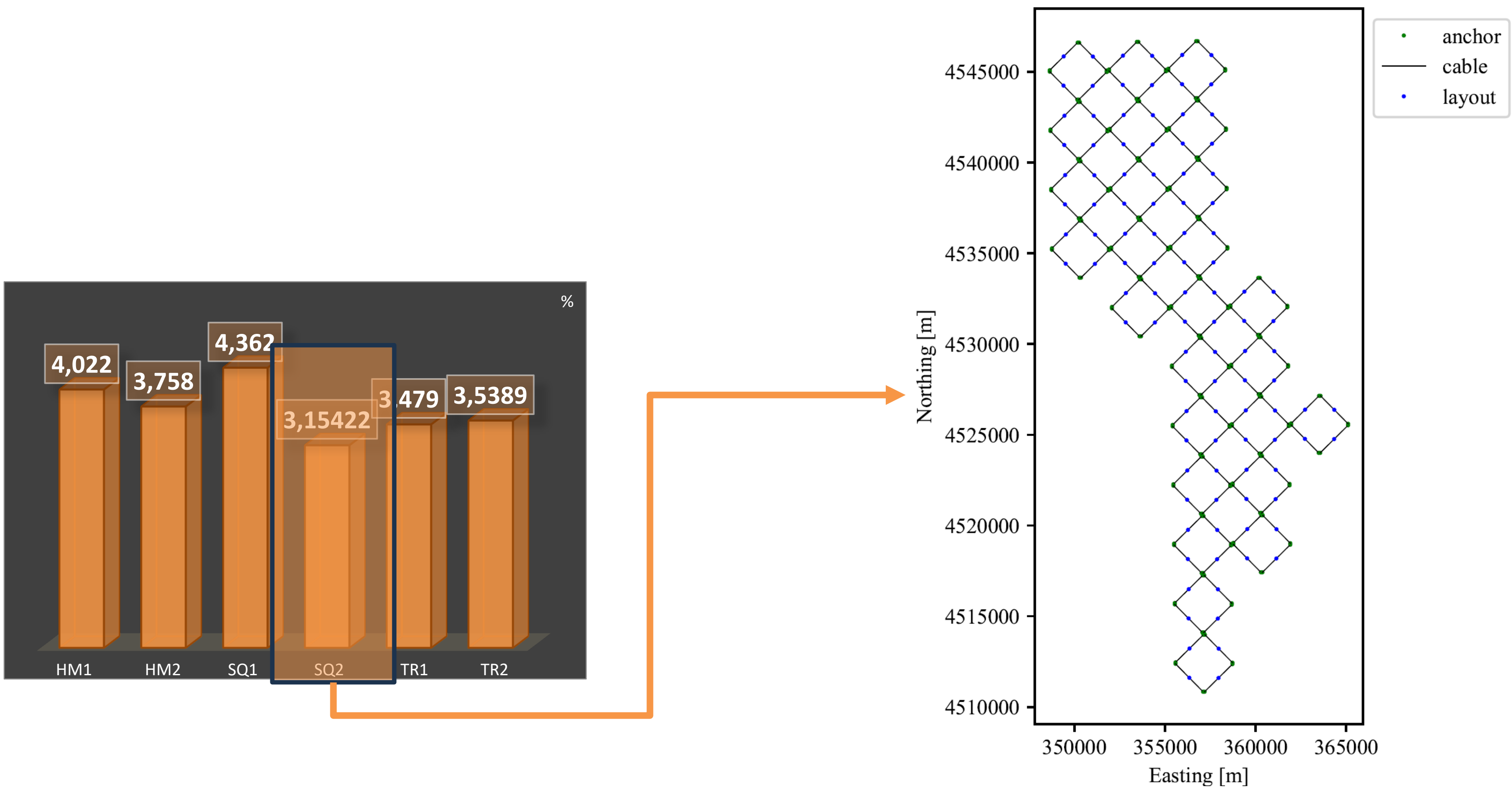
395,53
231,94
287,39
369,65
357,955
HM1
HM2
SQ1
SQ2
TR1
TR2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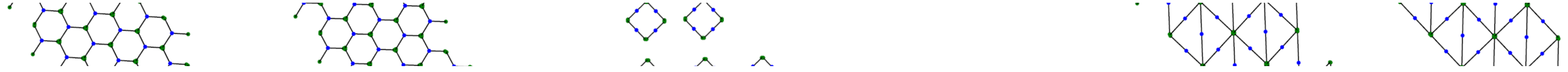

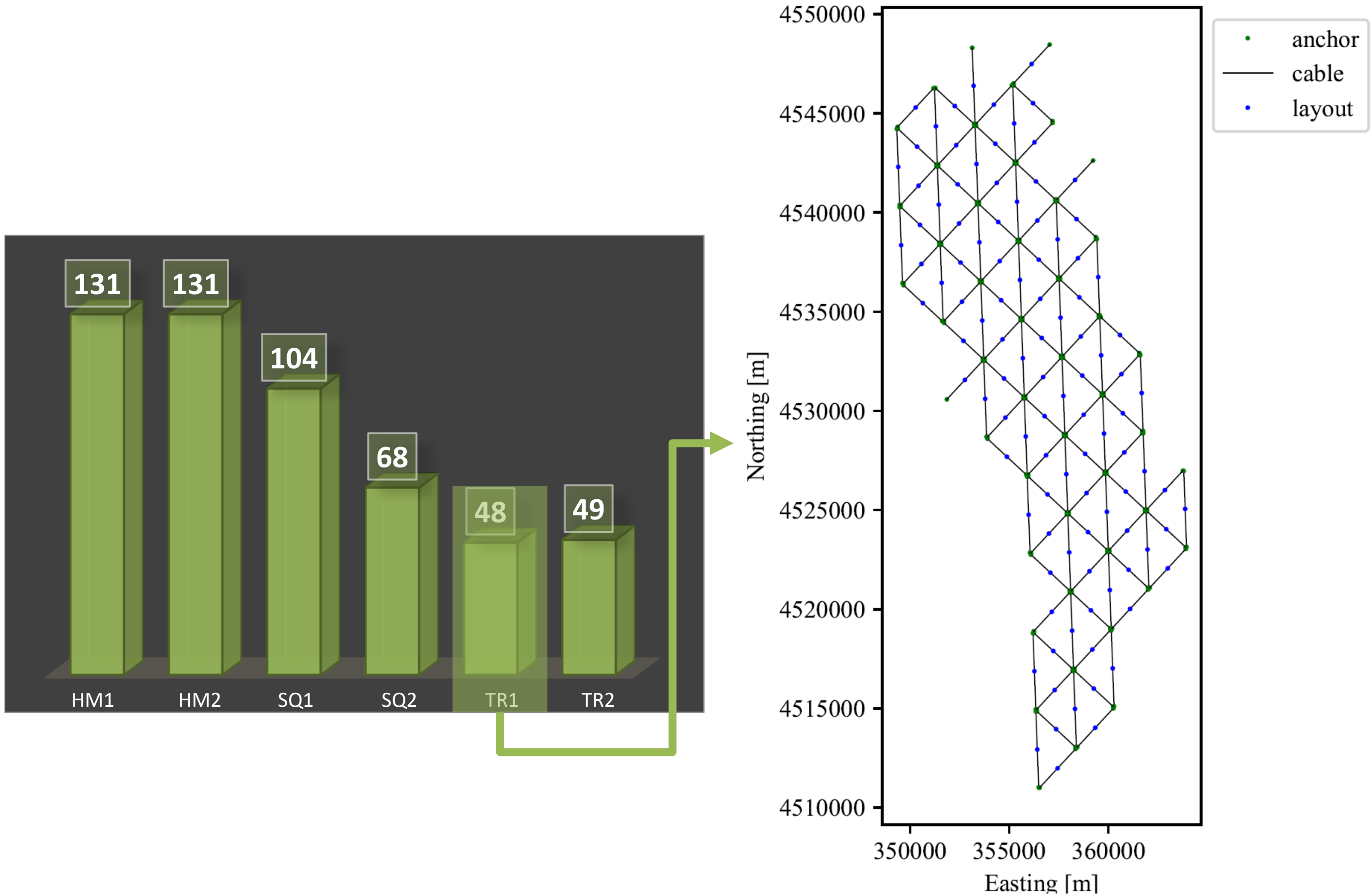
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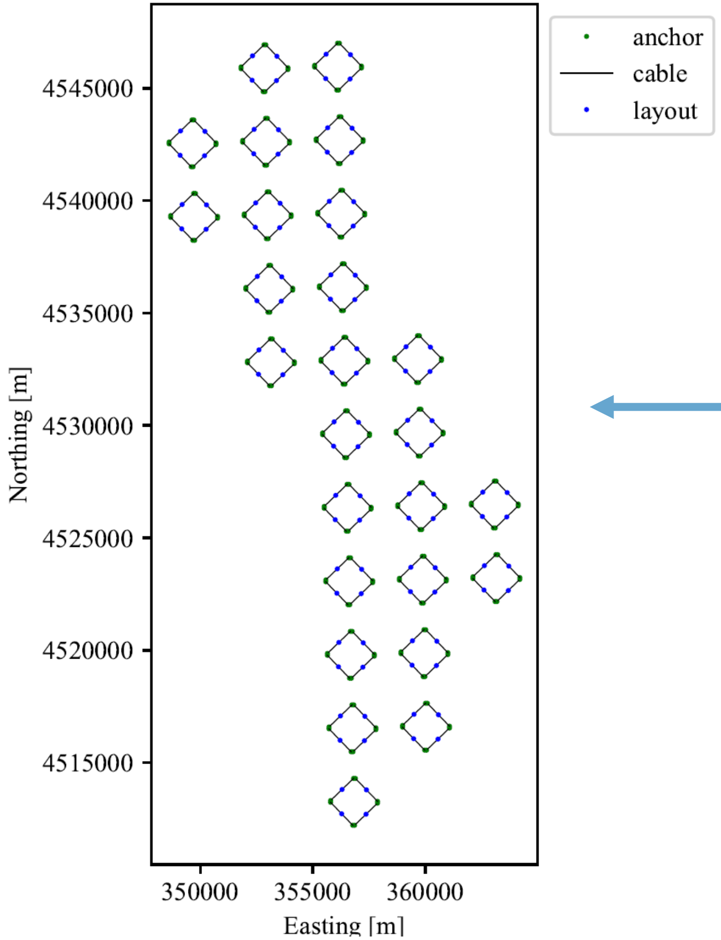
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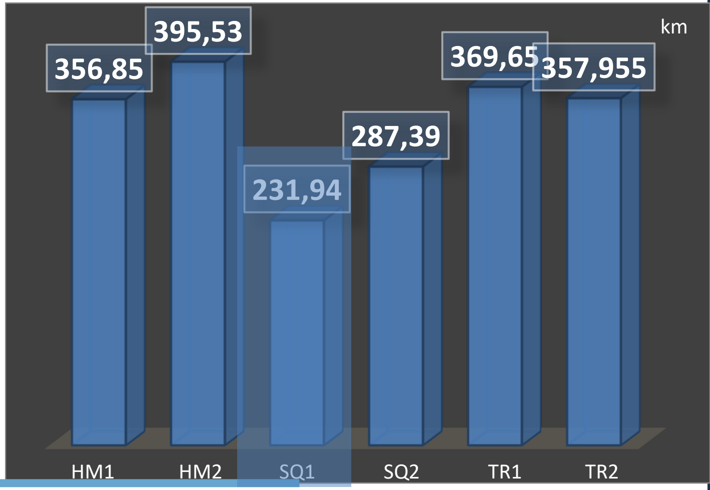
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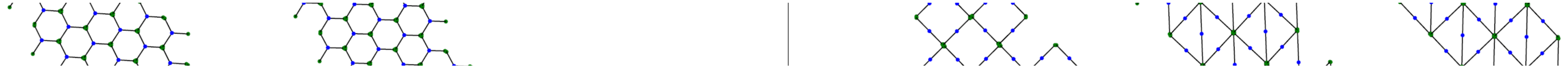
395,53
231,94
287,39
369,65
357,955
HM1
HM2
SQ1
SQ2
TR1
TR2



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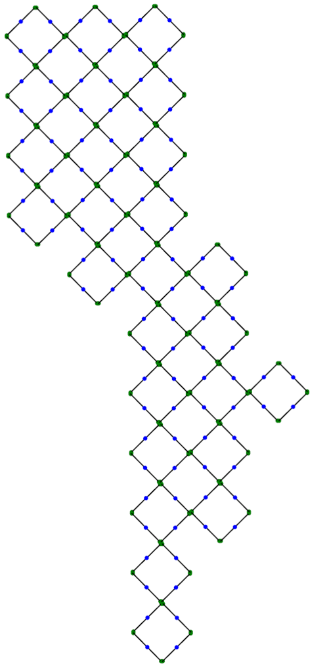
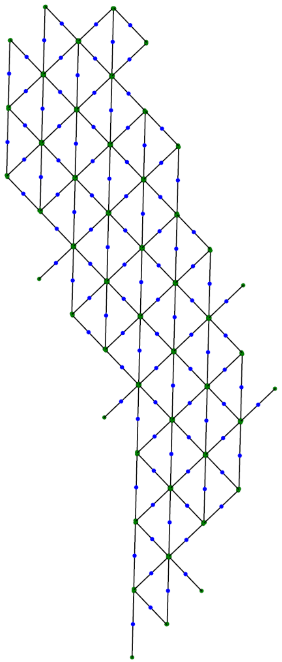
Humboldt – Turbine Clusters Optimization Problem

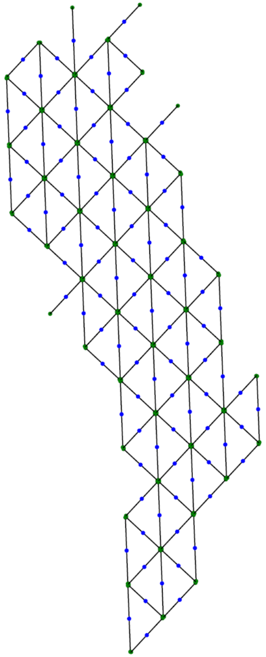
1 **Square (2)**



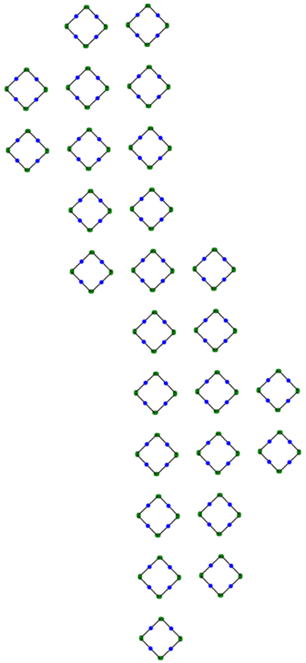
2 **Triangular (2)**



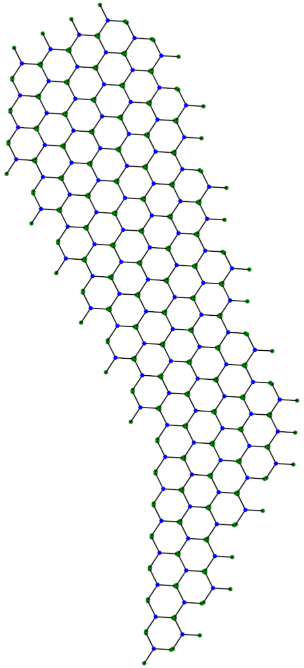
3 **Triangular (1)**



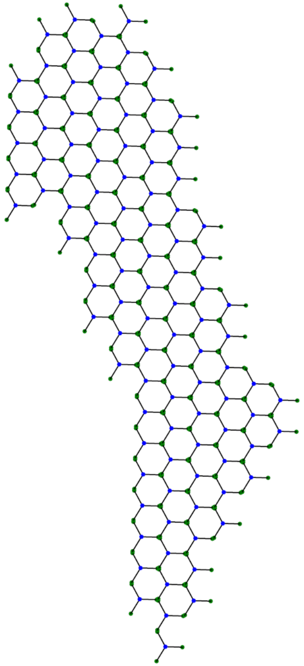
4 **Square (1)**



5 **Honeymooning (2)**

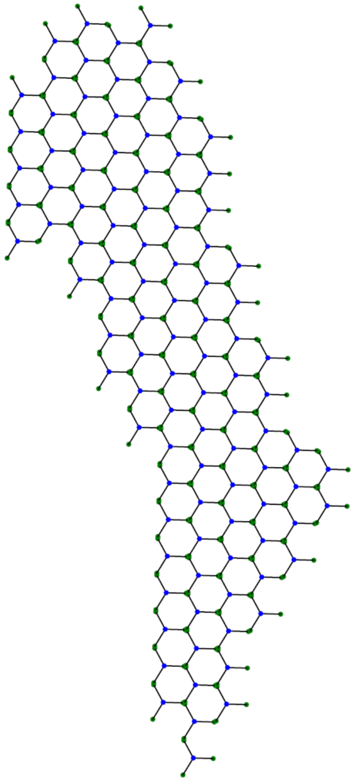


6 **Honeymooning (1)**



Humboldt – Turbine Clusters Optimization Problem

Honeymooring (1)



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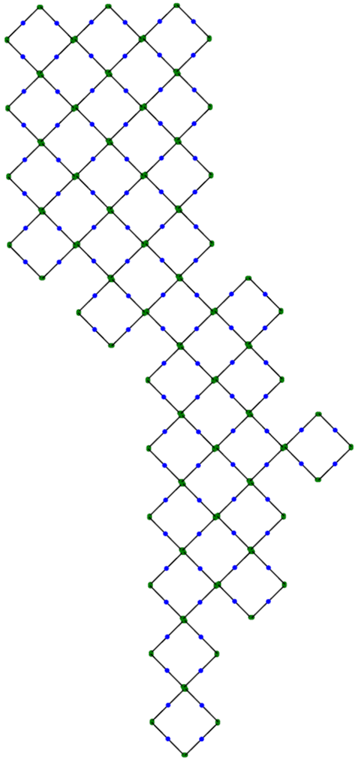
Square (2)



20% less wake effects

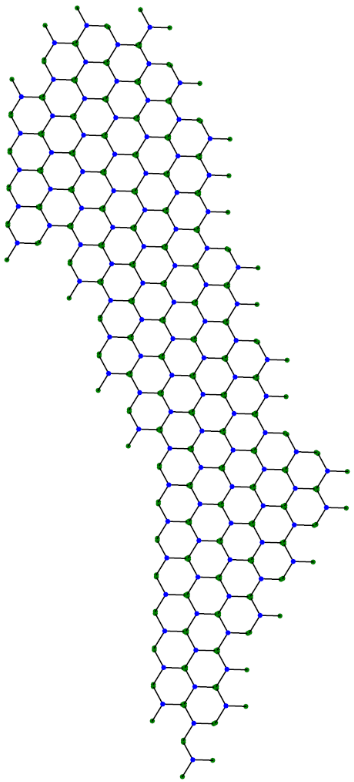
1% more AEY = 7000 US Households / yr

48% less anchors

20% less mooring cover

Humboldt – Turbine Clusters Optimization Problem

Honeymooring (1)



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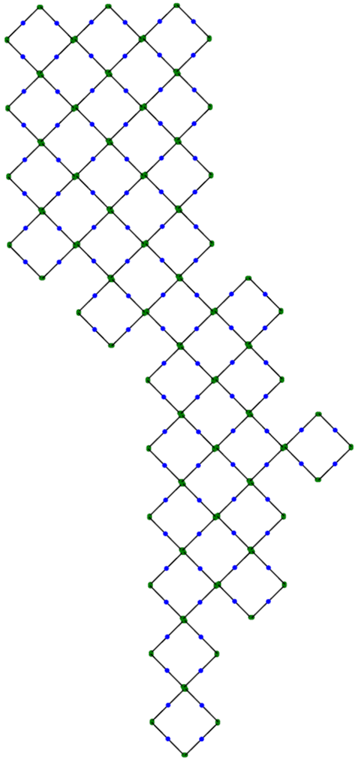
Square (2)



Preliminary upcoming results

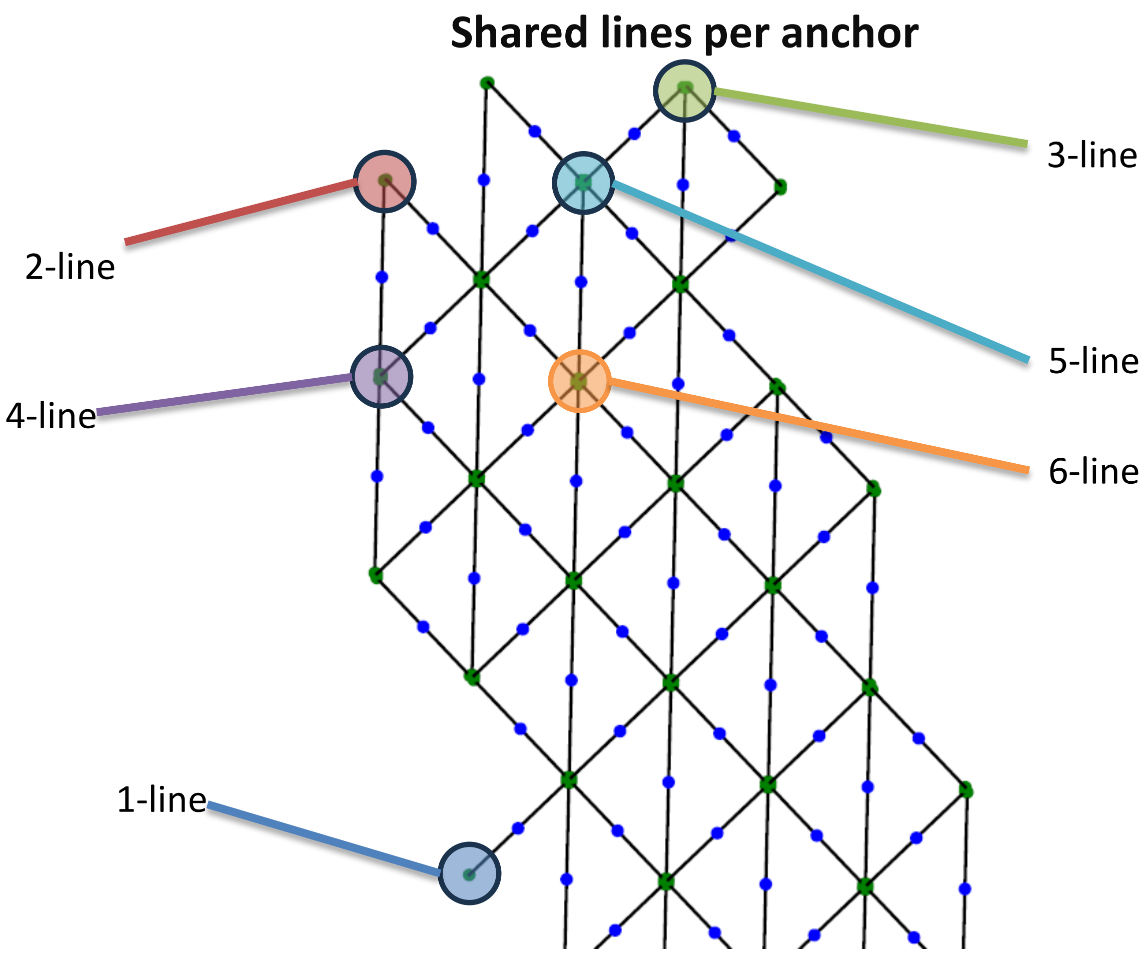
33% less wake effects

1.5% more AEY = 10750 US Households / yr

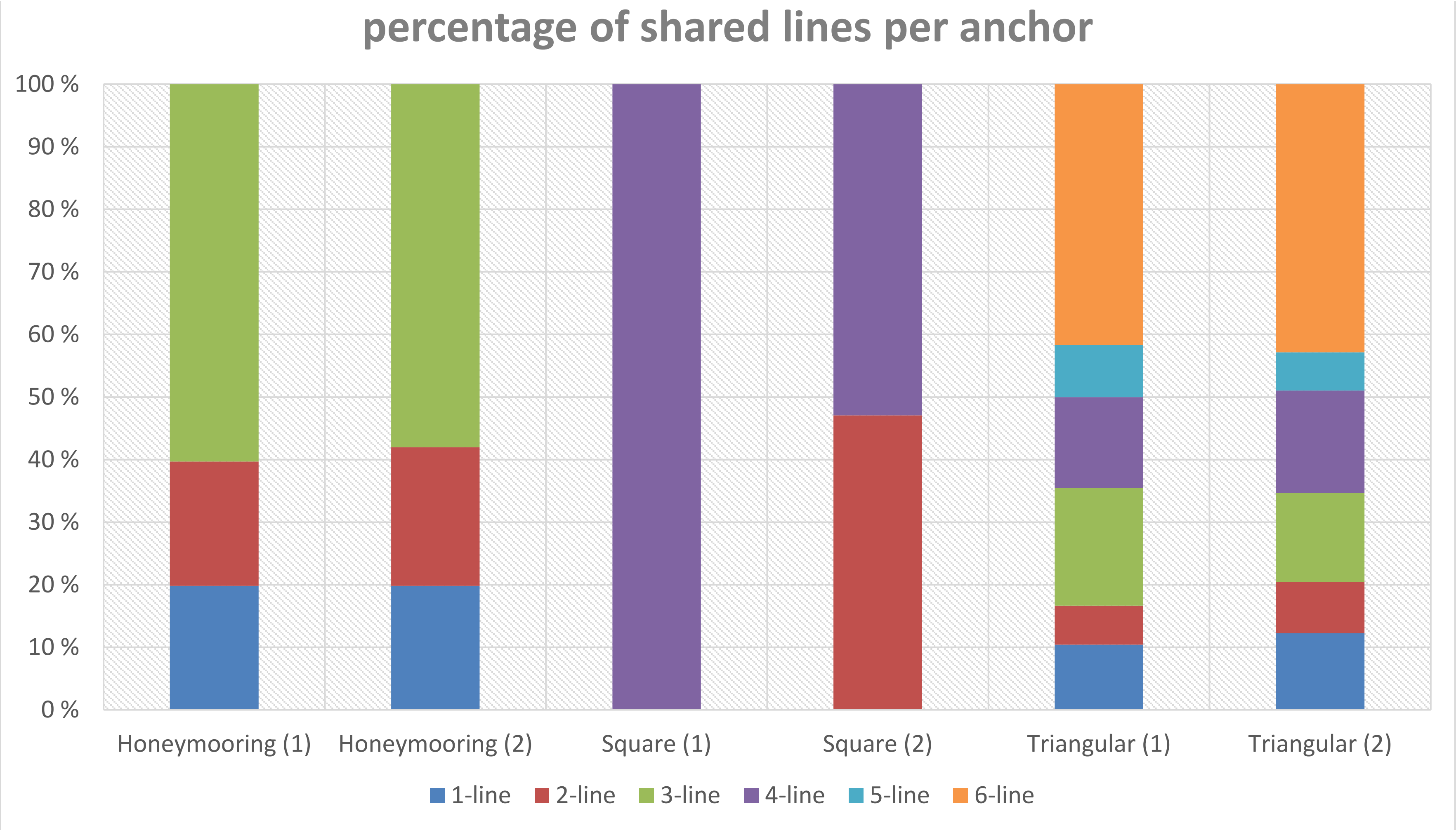
48% less anchors

20% less mooring cover

Humboldt – Turbine Clusters Multi-Objective Optimization Problem (MOOP)



Humboldt – Turbine Clusters Optimization Problem



Conclusion

- ASYMoor is a **design technique** aims to **simplify mooring setup** for floating offshore wind farms while keeping losses due to **wake at minimum**
- Sensitive Analysis demonstrates the effectiveness of this technique in reducing wake effects when wakes are dominant
- Turbine Cluster with 2-Mooring configuration has the potential to **reduce spacing** originally required between turbines as wake losses can be minimized via the repositioning of the turbines
- ASYMoor technique can be highly beneficial when the developer is aiming to **minimize mooring and anchor usage in the farm**.
- ASYMoor Square mesh is optimal for a multi-objective optimization of the Humboldt SW case study wind energy lease area, followed by a triangular mesh.
- ASYMoor Cluster, while is not optimal for energy production, is optimal in reducing mooring and anchor footprint

Possible Work Continuation

- Anchor and mooring load analysis
- Assessment and enhancement of modelling assumptions
- Umbilical design
- Investigation of dynamic performance
- Anchor placement near lease area boundary and establishing setbacks
- Synthetic robe
- Optimal watch circle and various mooring designs

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Dr. Amrit Verma

Prof. Amir Nejad

Prof. Erin Bachynski-Polić

and others…

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Thank you

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