PEAK Wind in collaboration with DTU

Techno-economical Layout and Turbine Type Optimization for Floating Offshore Wind Farms: A ScotWind Portfolio Study

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Floating Offshore Wind and the Use of Optimization

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Floating offshore wind

ScotWind's seabed tender

Significant milestone in the **commercial deployment** of **floating** offshore wind farms.

25 GW of offshore wind capacity, more than **half of it** concerns **floating**.

Stronger and more **stable winds**

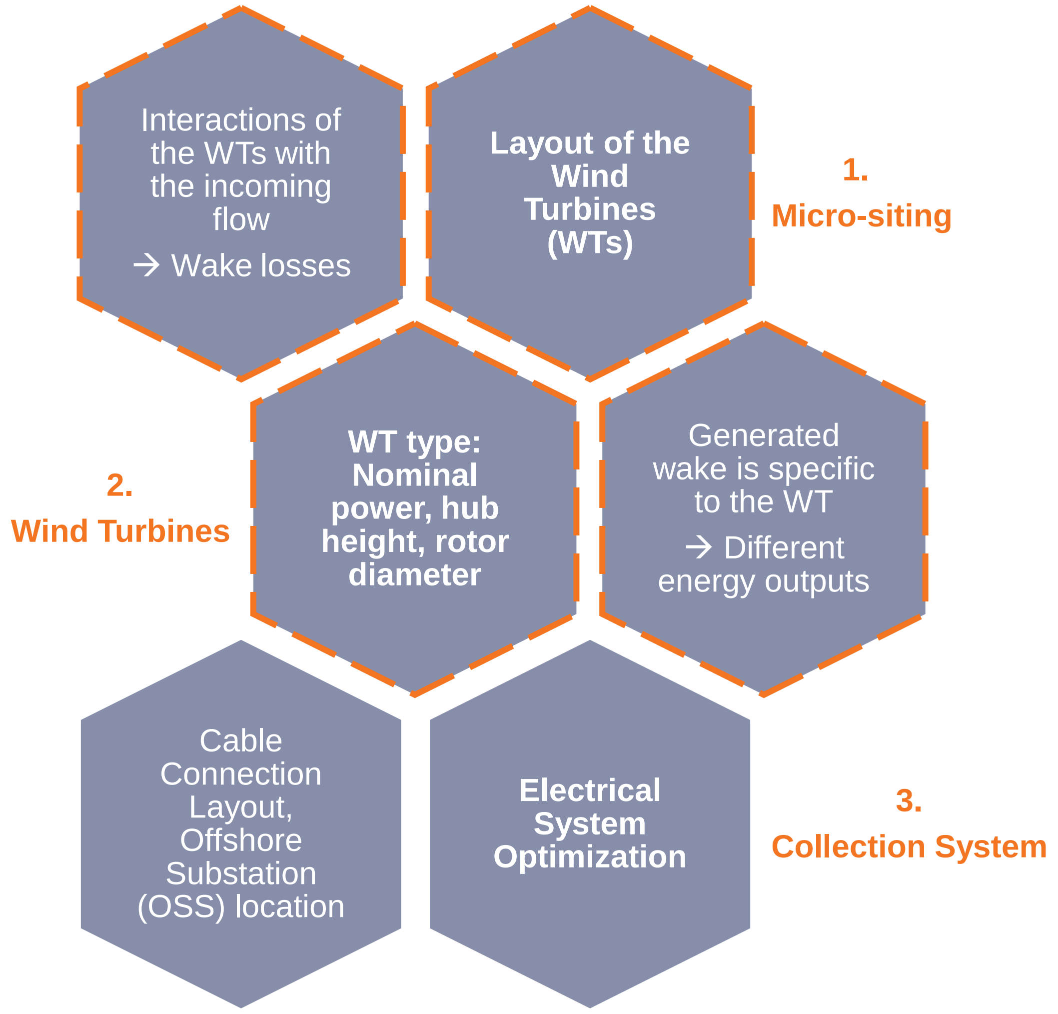
Better **social acceptance**

Larger areas

Still a relatively **immature** but rapidly **growing technology**

Higher costs than bottom-fixed

Optimizing the AEP and LCOE of offshore wind farms



Scope of Work

Techno-economical Layout and Turbine Type Optimization for Floating Offshore Wind Farms: A ScotWind Portfolio Study

Highlight and quantify the **benefits of optimization on the AEP and LCOE** for 3 **different ScotWind floating wind projects.**

Investigate several optimization methods using **state-of-the-art algorithms**.

Conduct **sensitivity analyses** on crucial inputs to understand the impact on the results.

Assess the different **trade-offs** in terms of **performance and costs** at different **levels**: **Turbine – Wind Farm – Portfolio** (across the 3 **different projects**)

Site #	Cap capacity [MW]	Area [km²]	Density [MW/km²]	Mean water depth [m]
10	500	134	3.73	90
11	3000	684	4.39	100
2	2610	859	3.04	73

For each site, 3 different WTs are investigated

WT manufacturer	Single capacity [MW]
Siemens Gamesa	11
Siemens Gamesa	14
Vestas	15

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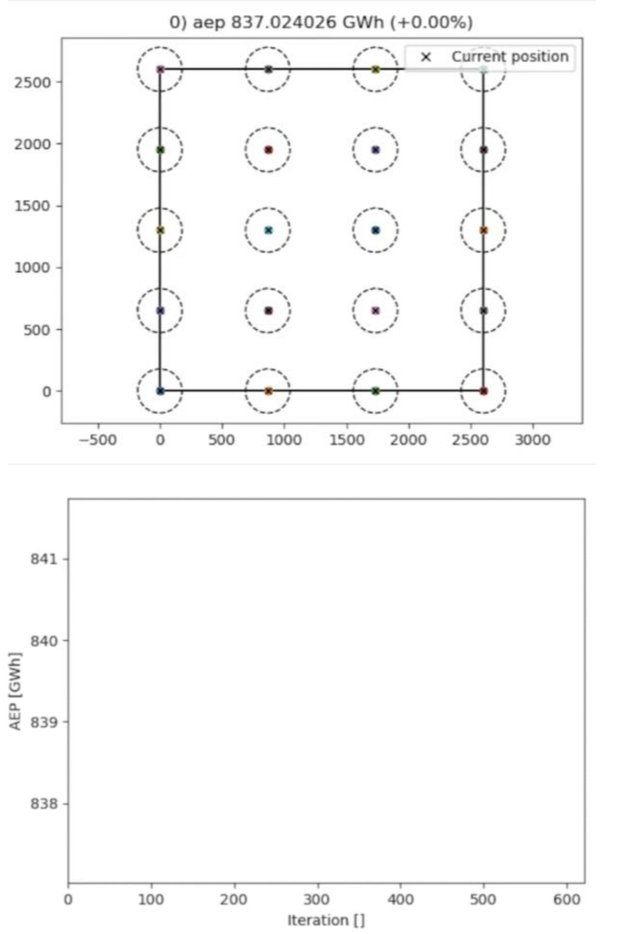
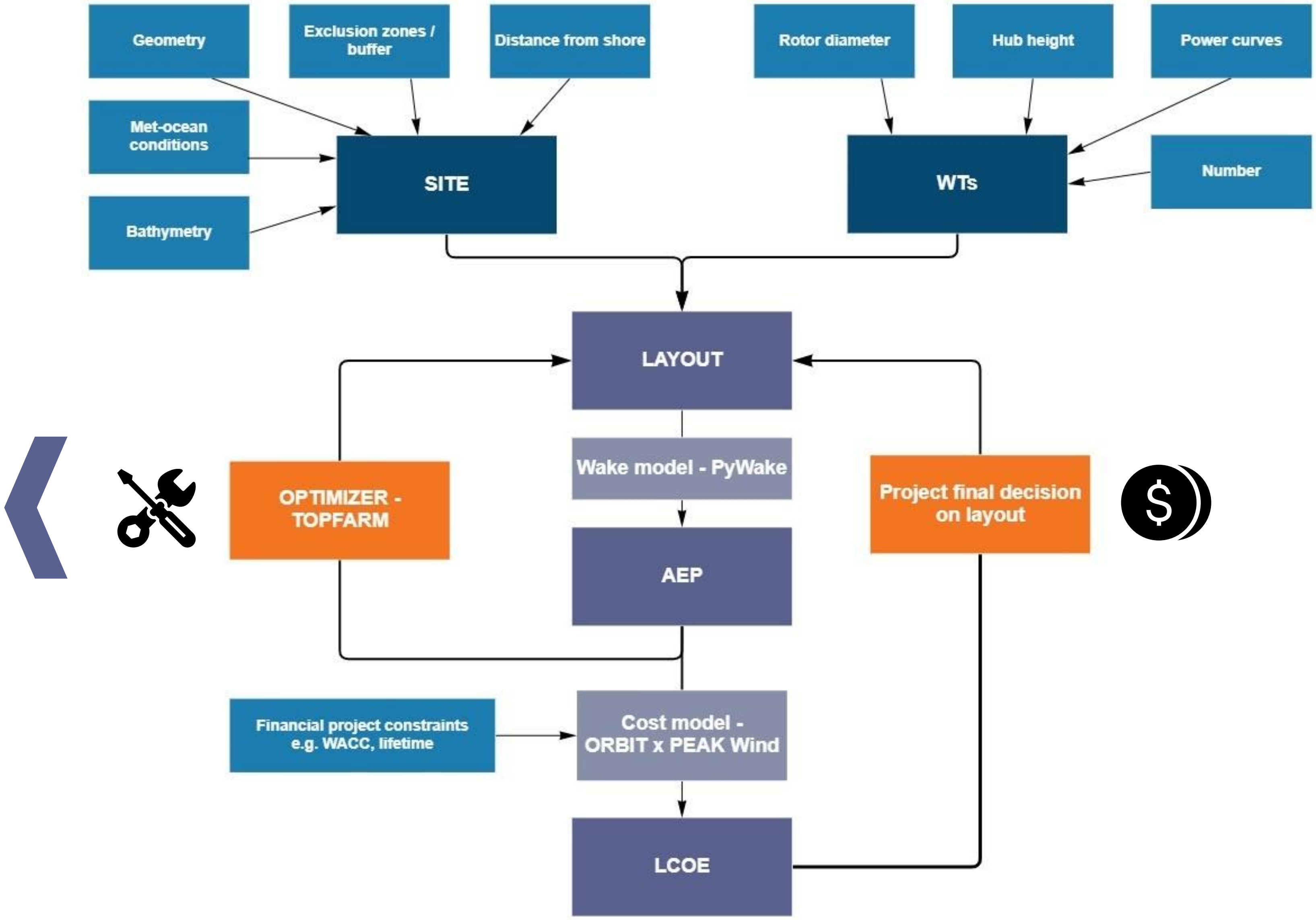
Flowchart: Overview of the Model



Visualization of an optimization



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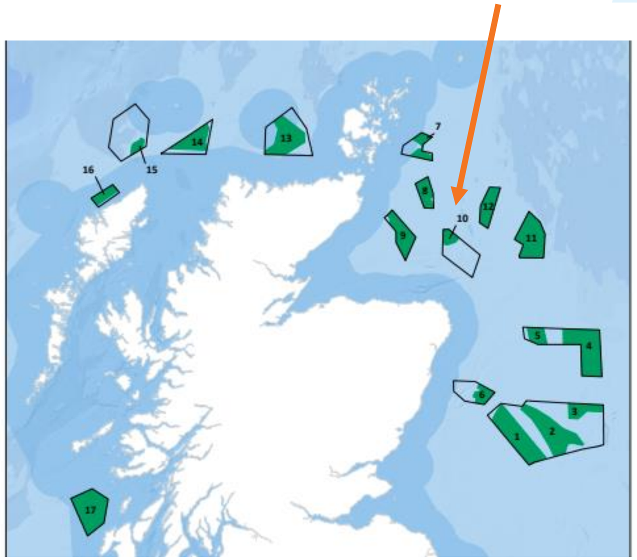
Site 10 (500 MW)

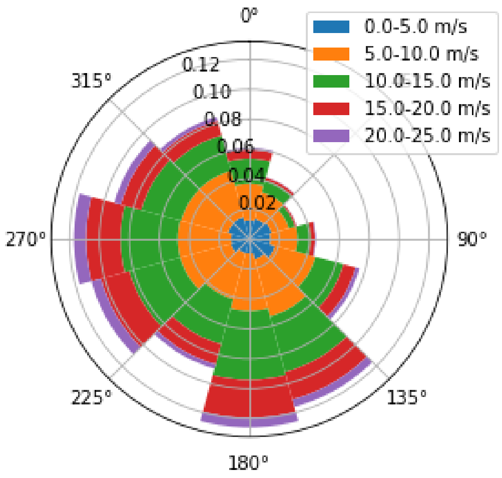
Case study set-up

Inputs

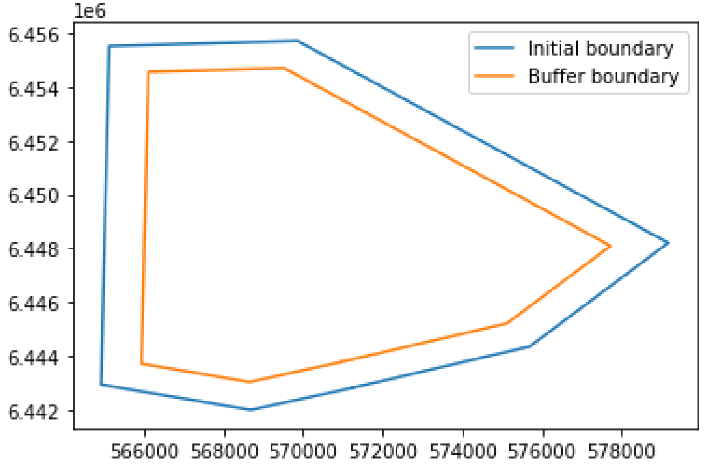
Site	**Irregular geometry (.GIS data) with buffer** **Area: 134 km^2**
Set of WTG	V236 15 MW SG 14.0-222D SG 11.0-200D
Station keeping system	Semi-submersible substructure 3-line catenary mooring system DEA anchors
Metocean conditions	**Real wind data from the site location** **Water depth: 90 m**
Wake model	Bastankhah Gaussian
Project parameters	Project duration: 30 years WACC: 8% Non wake-related losses: 9%



Location of the site



Wind rose of the site



Geometry of the site

Comparison of the optimized layouts and AEP

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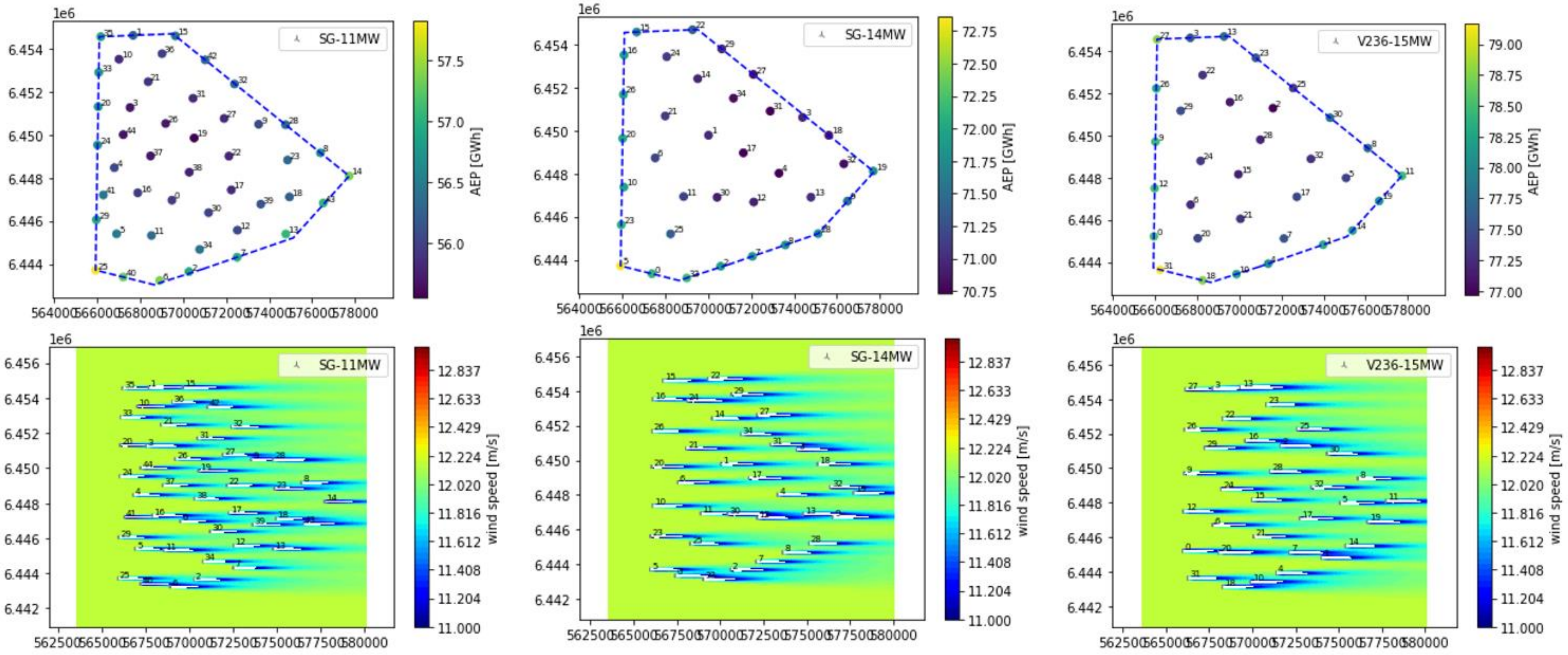
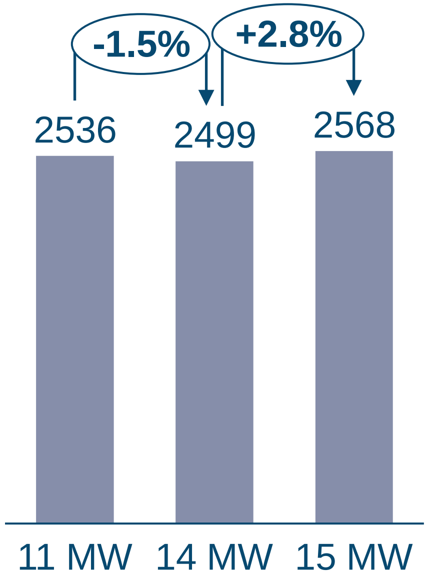
45 11 MW WTs	WT capacity ↗ / # of WTs ↘	35 14 MW WTs	WT capacity ↗ / # of WTs ↘	33 15 MW WTs

Optimized **gross AEP [GWh]**
for **each configuration**



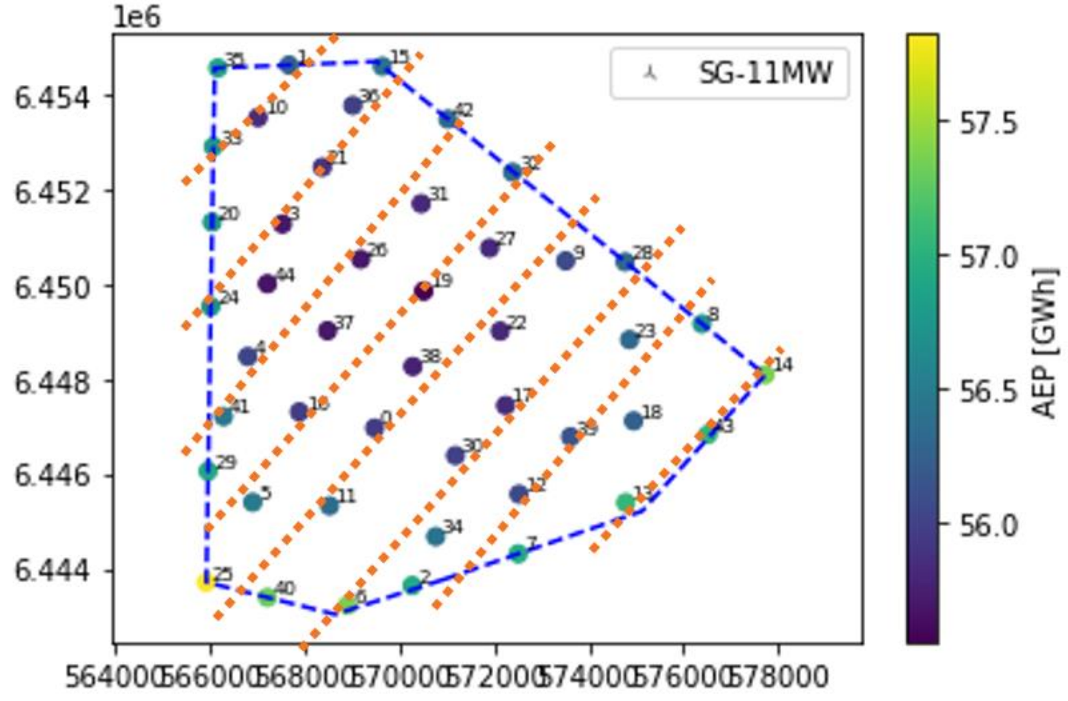


→ Using 11 MW turbines leads to a higher gross AEP compared with 14 MW turbines due to the site-specific complex interactions with the incoming flow.

→ The 15 MW turbines allow to maximize the energy production even more, as the higher spacing allows an increase in relative wind speed.

Trends in the optimized layouts

Key take-aways



Trend lines in the positioning of the WTs

→ The WTs occupy the **maximum space** to **maximize the energy capture**.

→ The ones placed close or even **on the borders** produce **more energy** than the ones towards the inside (**+2.7%**) as they face **stronger winds** that are not subject to wake losses yet (especially lower left bounds).

→ The WTs are quite **aligned** in the **south-west**, **dominant wind direction.**

→ In the dominant wind direction, the WTs have a **slight offset** to move **out of the wake** of the WT in **front** and thus to **reduce the wake losses**.

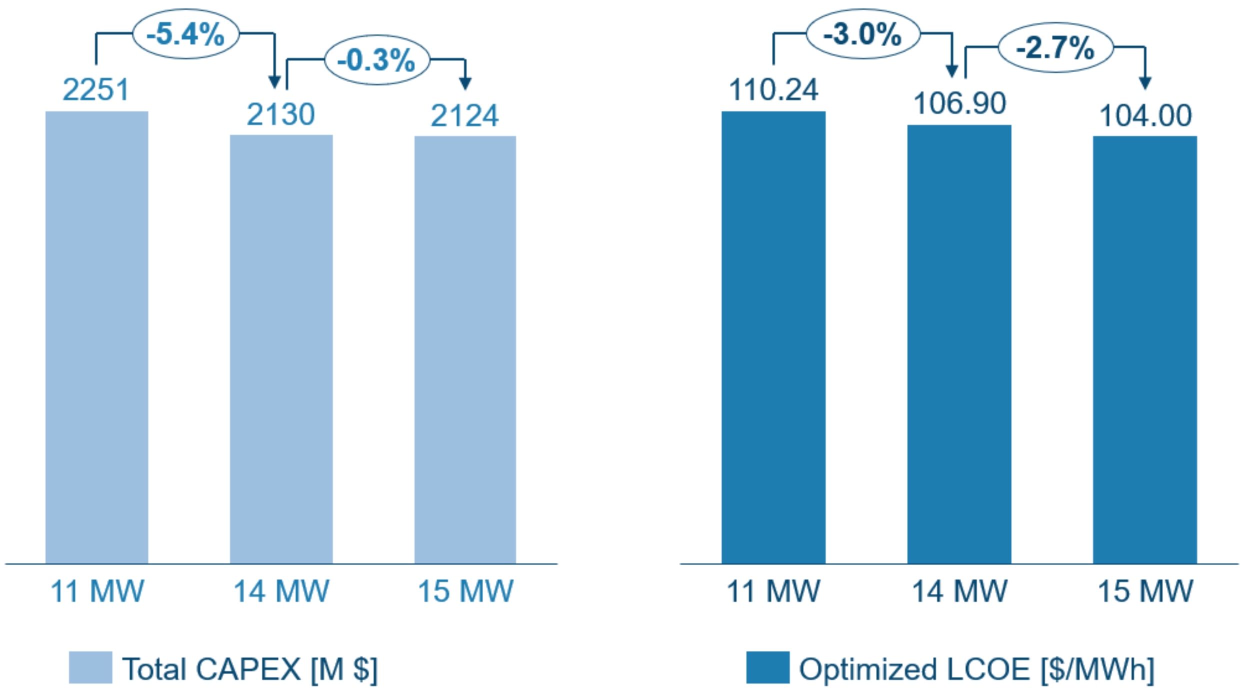
Total CAPEX and LCOE

Key take-aways

→ The **total costs decrease** with the **increase in nameplate capacity** of the WTs, as **costs are saved** when **using less WTs** (procurement of the **WTs**, **substructures**, less **mooring lines** and anchors needed, **shorter cable routes**).

→ Overall, the major drop in CAPEX between 11 MW and 14 MW WTs counterbalances the slightly higher AEP → LCOE decreases.

→ The LCOE are consistent with the projections for the coming years linked with the **commercial deployment** of **floating offshore wind farms** and the **induced cost reductions** (economy of scale) (Catapult Offshore Renewable Energy, 2021).



The results are consistent with the upscaling trend observed in the industry (« the bigger turbine, the better »).

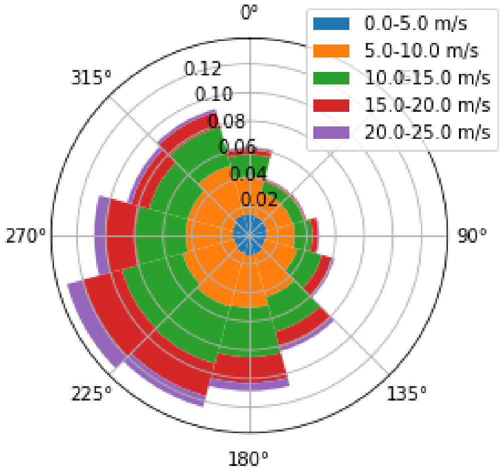
Site 2 (2610 MW)

Case study set-up

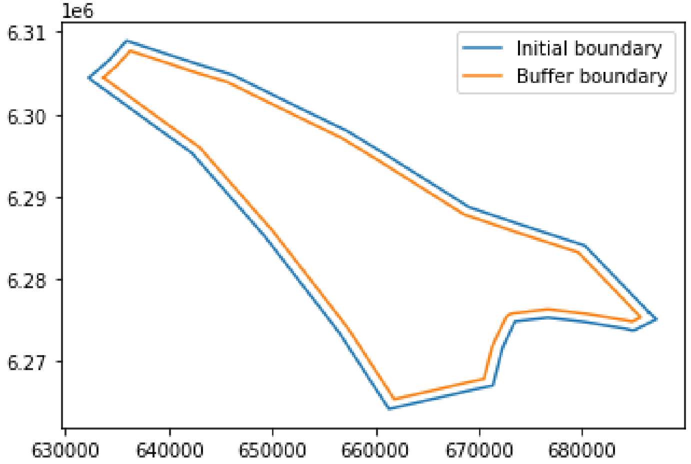
Inputs

Site	▪ **Irregular geometry (.GIS data) with buffer** ▪ **Area: 859 km²**
Set of WTG	▪ V236 15 MW ▪ SG 14.0-222D ▪ SG 11.0-200D
Station keeping system	▪ Semi-submersible substructure ▪ 3-line catenary mooring system ▪ DEA anchors
Metocean conditions	▪ **Real wind data from the site location** ▪ **Water depth: 73 m**
Wake model	▪ Bastankhah Gaussian
Project parameters	▪ Project duration: 30 years ▪ WACC: 8% ▪ Non wake-related losses: 9%

Location of the site



Wind rose of the site



Geometry of the site

Comparison of the optimized layouts and AEP

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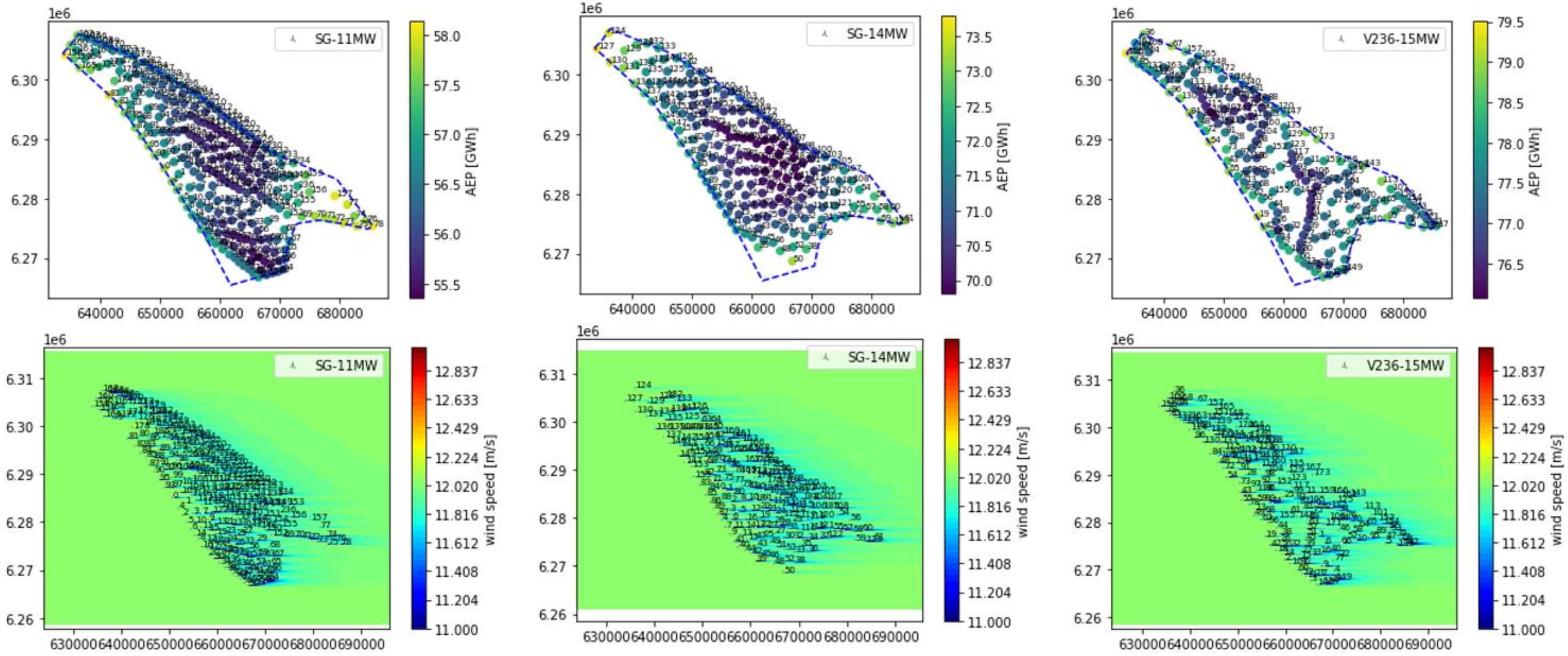
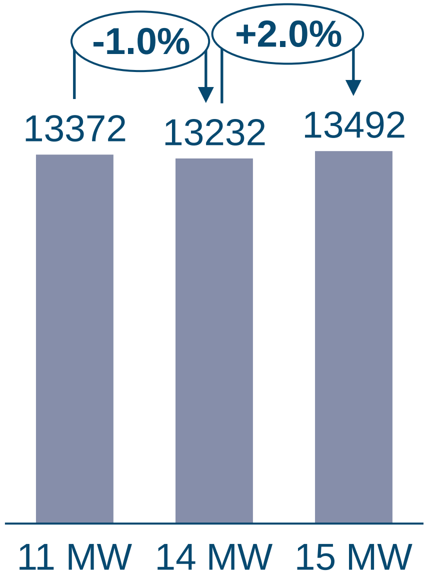
237 11 MW WTs — WT capacity ↗ / # of WTs ↘ — **186 14 MW WTs** — WT capacity ↗ / # of WTs ↘ — **174 15 MW WTs**

Optimized **gross AEP [GWh]** for **each configuration**





→ **Increased optimization complexity** due to the non-convex and irregular geometry of the site combined with the **huge wind farm power**. Some **empty areas** might indicate that the optimizer found a **local optima** instead of the **global** one. More **irregular** layout, trends and patterns difficult to extract.

→ Similarly to site #10, the **WTs on the borders produce more energy**. The same trend in **reduction of the AEP** from 11 MW to 14 MW and then **increase** from 14 MW to 15 MW is observed.

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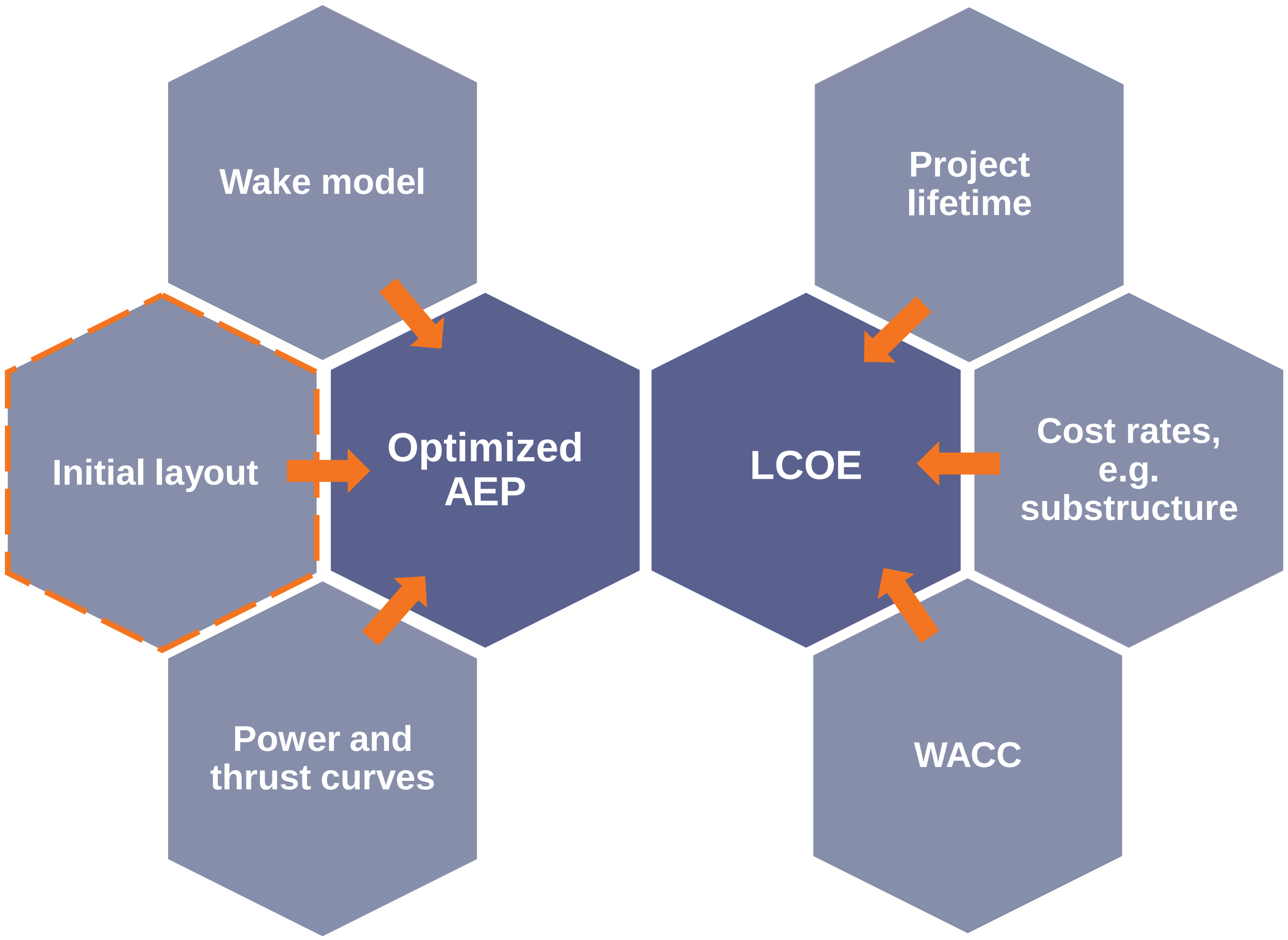
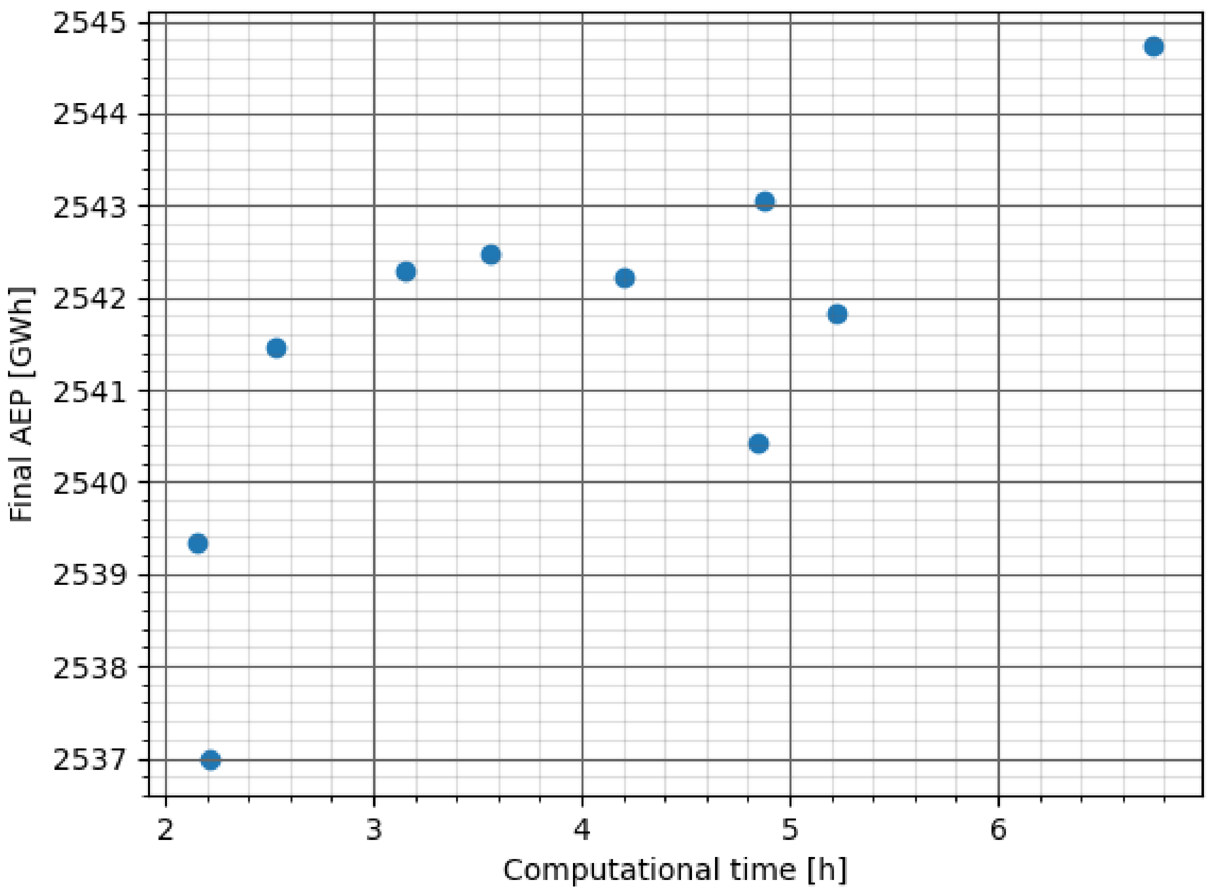
One-at-a-time Sensitivity Analyses

Using Site 10 – 500 MW



Impact of the initial layout on the optimized AEP

Bastankhah Gaussian wake model



Methodology:

- 10 randomly generated initial layouts that satisfy the constraints
- Same optimization algorithms, steps & parameters

Results:

- The computational time and the final AEP vary → Different **local optima**
- Correlation between time and final AEP
- Importance of a **multiple-start optimization strategy** to explore the whole design space

Multiple-step optimization strategy

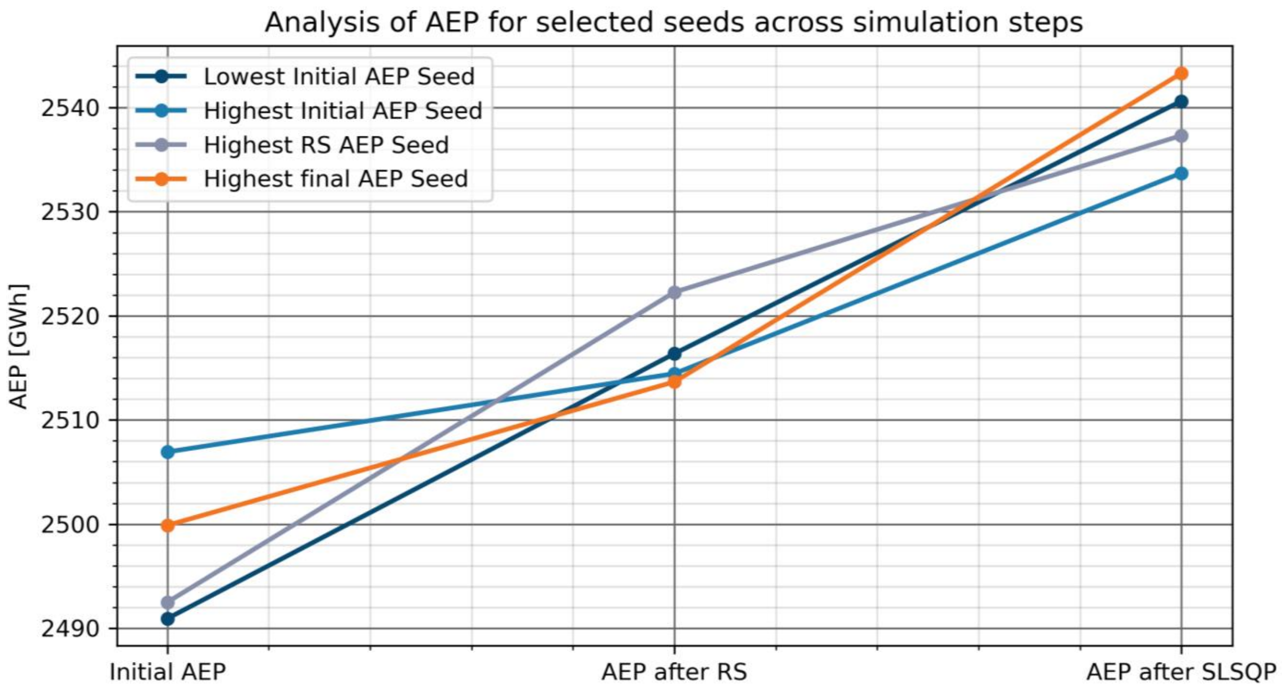
Impact of the optimization driver

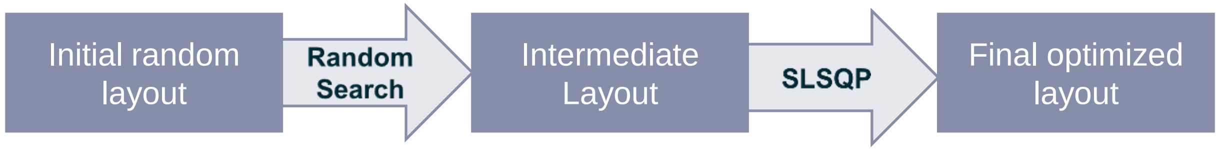
Methodology:

- Same 10 batches of randomly generated initial layouts
- **2 steps**: first **random search** (explores the wider design space), then **gradient-based algorithm**, SLSQP (Sequential Least Squares Quadratic Programming)

Results:

- Each optimization algorithm **increases the AEP**, but the **combination** of the two steps achieves the **highest gain**
- No correlation between initial and final AEP: highly **multimodal design space** with **many local optima**





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Thank you

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