EERA DeepWind conference

Contribution of reliability and interactions between turbines in the optimization of an offshore wind farm

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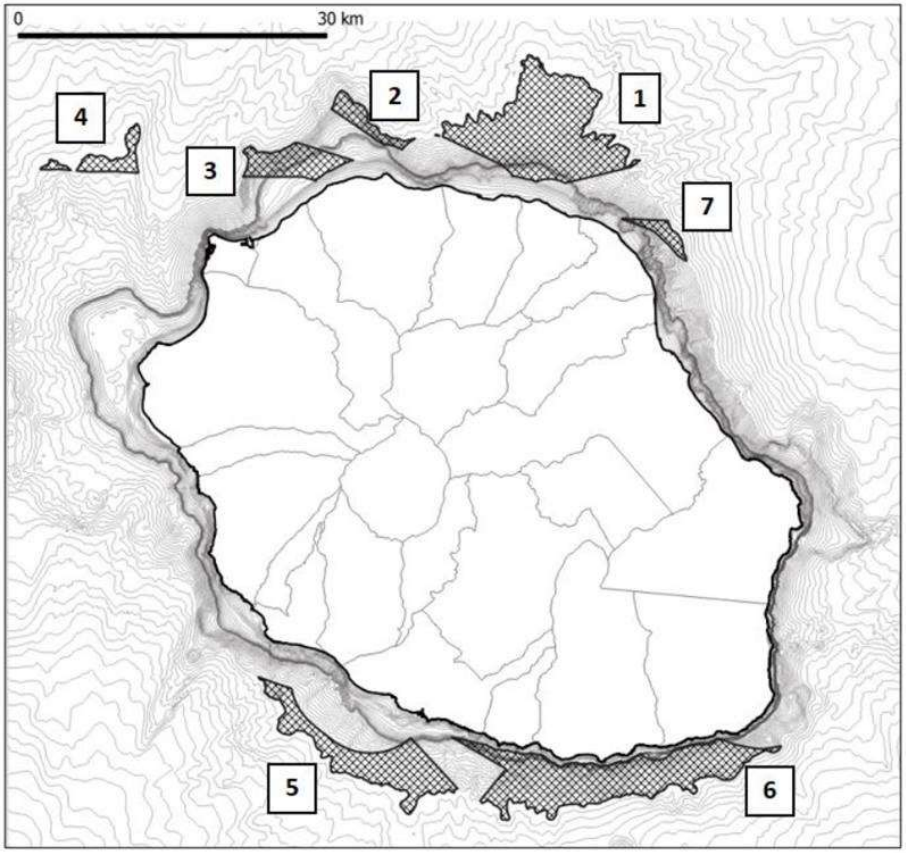
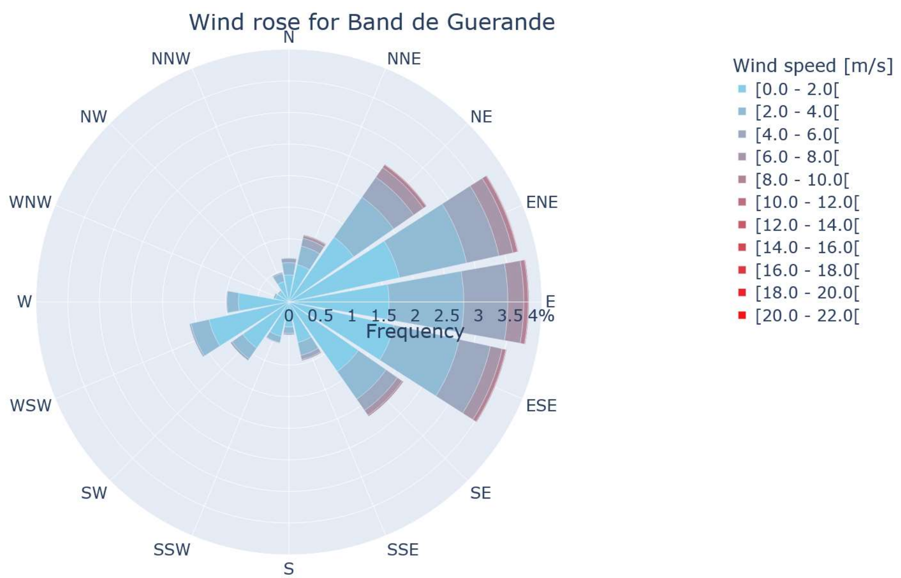
Context

- The Optile project focuses on studying the use of marine resources to power isolated sites. The primary case study is Reunion Island. This type of site is characterized by significant constraints, particularly regarding installation feasibility. As a volcanic island, its seabed drops off extremely quickly to considerable depths.
- The project explores various technologies, including floating wind turbines, floating photovoltaic (PV) systems, and wave energy converters, aiming to harness the island's natural potential. In addition to technological challenges, the project aimed at incorporating environmental and societal constraints, ensuring solutions are sustainable and align with local needs and ecosystems.
- Optile represents an innovative approach to addressing energy independence for remote islands while mitigating environmental impact and engaging local communities in the energy transition process.



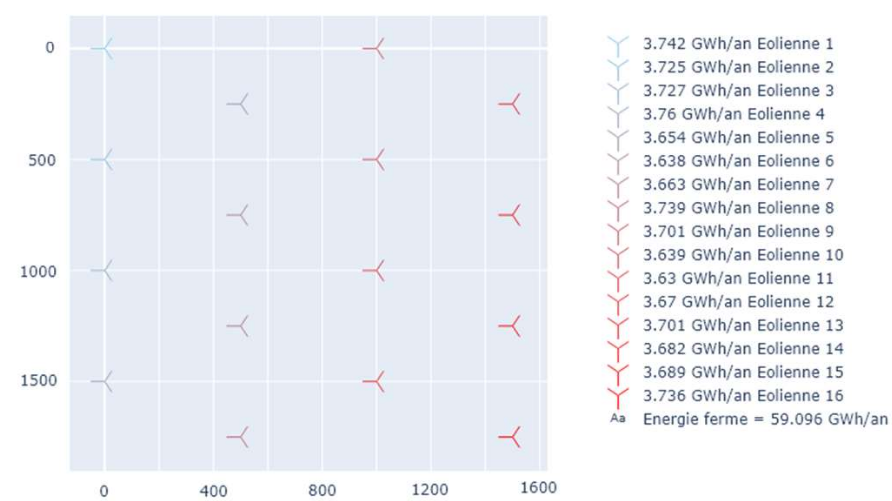
Resource estimation from Copernicus data



[1] H. Hersbach et al., « ERA5 hourly data on single levels from 1940 to present », ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS).

- The resource estimation is carried out based on wind data. In this case, the data comes from the Copernicus database [1].
- The Gaussian Jensen model is used, it demonstrates excellent correlation with wind tunnel tests [2] and offers a good trade-off between representativeness and computational speed.

Resource estimation



Estimation / optimization of inter-array cable

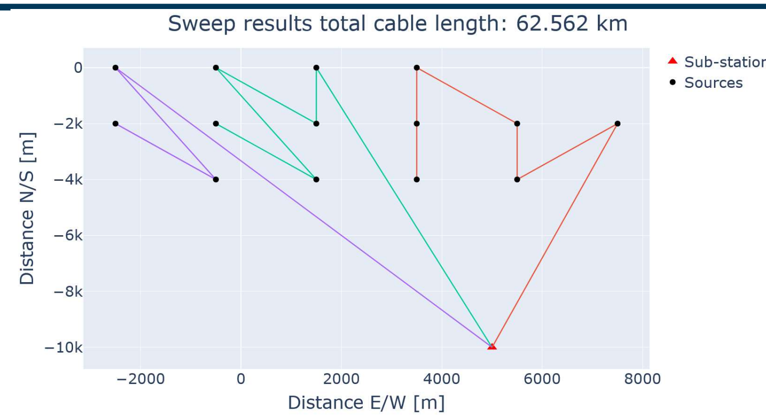
To estimate the length of inter-array cables within a wind farm, an algorithm based on the **Variable Neighborhood Search (VNS)** method is used. This algorithm solves an optimization problem by exploring different configurations of wind turbine groups.

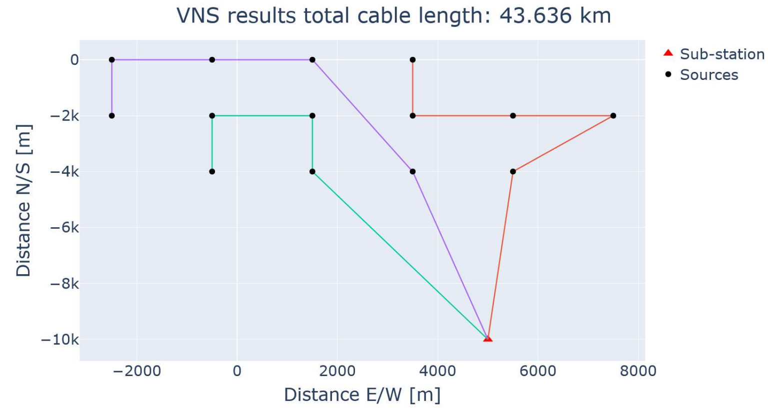
- **Constraints and Method**

- Power Constraints:
The estimated production of all turbines is used to constrain the number of turbines per *array*. The total power of a group must not exceed the nominal capacity of the selected cable.

- Initialization:
The initialization of the algorithm is performed using a **Sweep** heuristic method, which provides an initial solution based on the geographical layout of the turbines.

- Objective:
The primary objective of this optimization is **to obtain a realistic estimation of the connection between the machines,** with the aim of defining cable lengths between the machines and determining the associated losses and reliability.

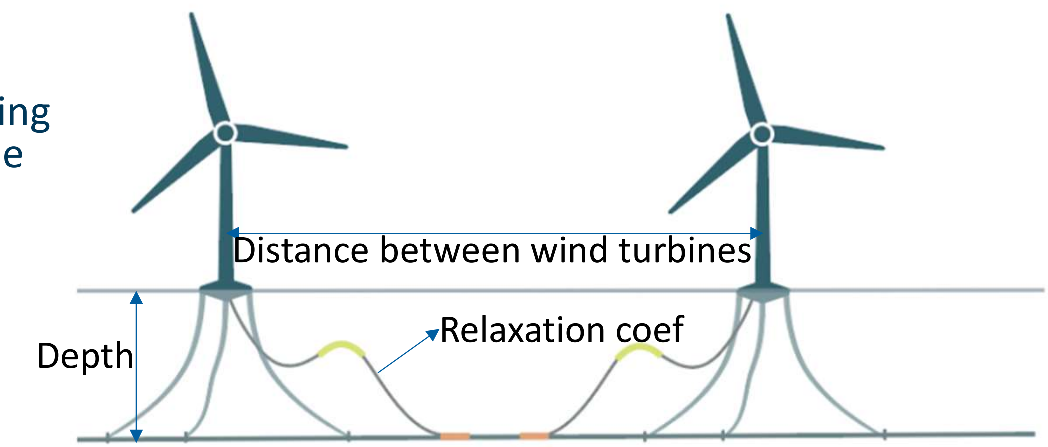




Loss and reliability calculation

- Once the turbine groups and their respective distances are defined, the total cable length is evaluated by adding:
  - **Twice the average water depth** of the wind farm, weighted by a relaxation coefficient.

This solution enables us to dynamically adjust cable lengths to accommodate any possible wind farm configuration, ensuring optimized design and achieving more accurate and reliable outcomes. By tailoring the cable layout to specific project requirements, we enhance the overall performance, reduce energy losses, and improve system performances.



These cable lengths are then used to evaluate:

Joule losses in the cables, based on their resistance and the flow of the power.

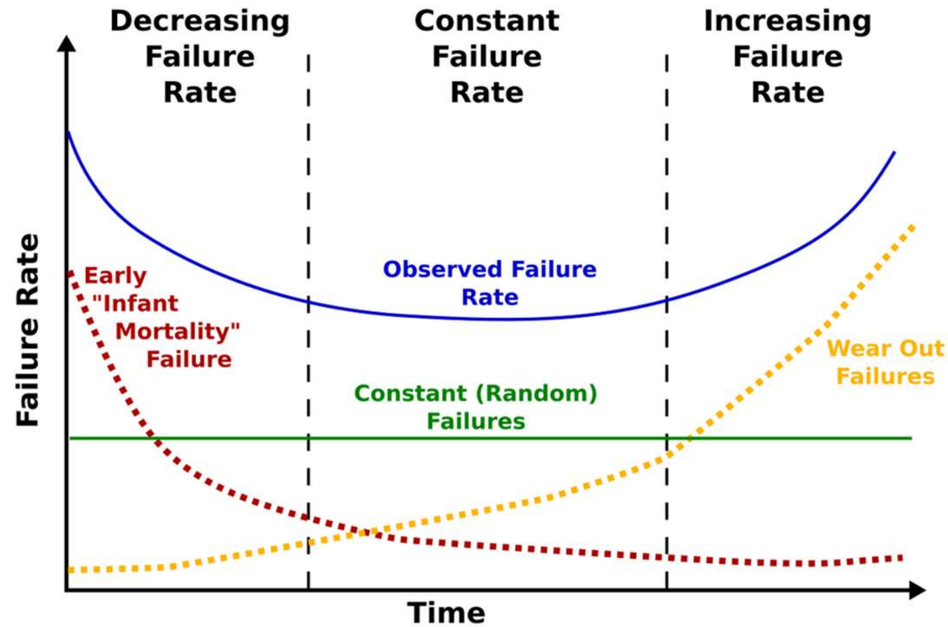
Cable reliability, which, for now, is modeled as a function of their length.

Reliability analysis

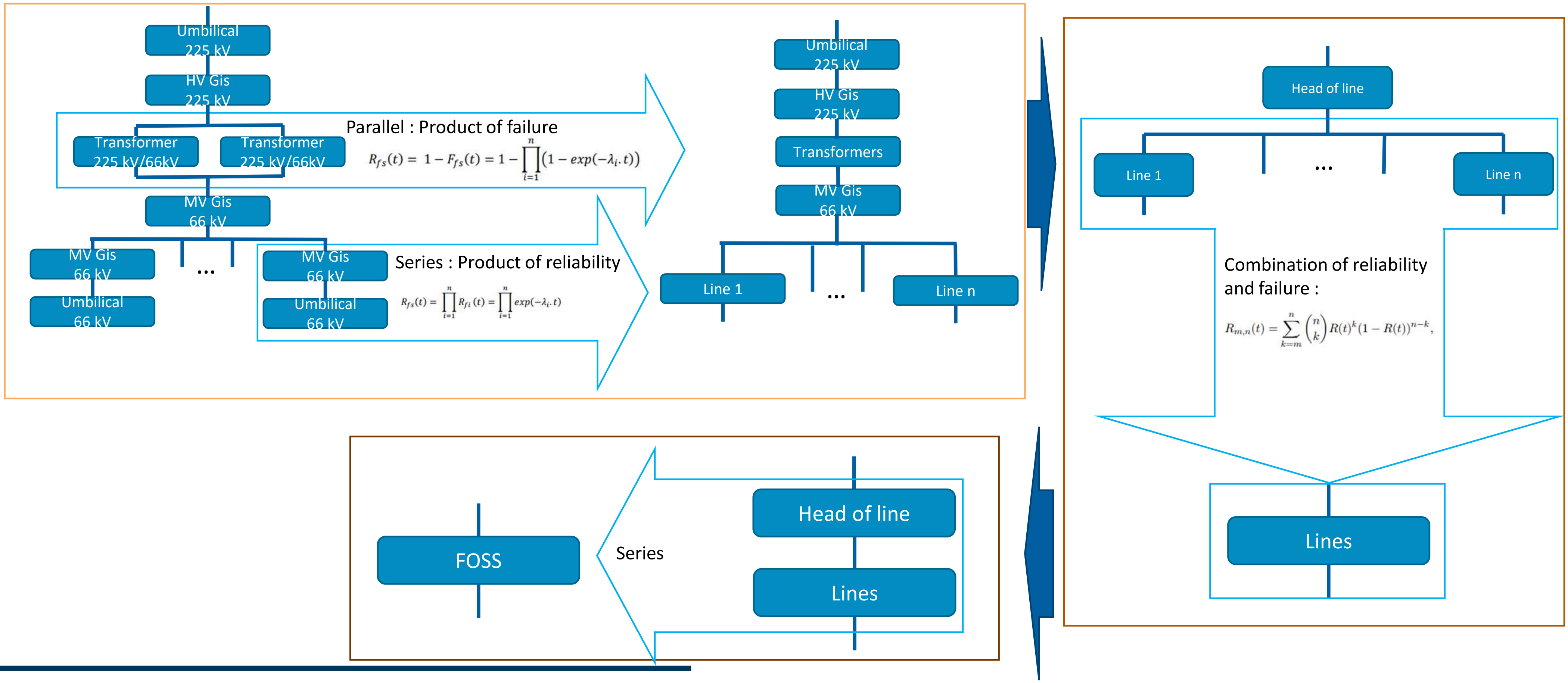
- The reliability method used in this project is based on the principles of Reliability, Availability, Maintainability, and Safety (RAMS). This approach, derived from the field of infrastructure maintenance, aims to ensure optimal management of the performance and durability of complex technical systems. It primarily relies on the evaluation of a key reliability indicator, determined by aggregating multiple interconnected subcomponents and assessed through their "Mean Time to Failure" (MTTF).

- The method we use considers only the "Wear Out Failure" curve, assuming that the systems studied are critical and thus free of early-life defects.
- This curve is approximated by an exponential law:

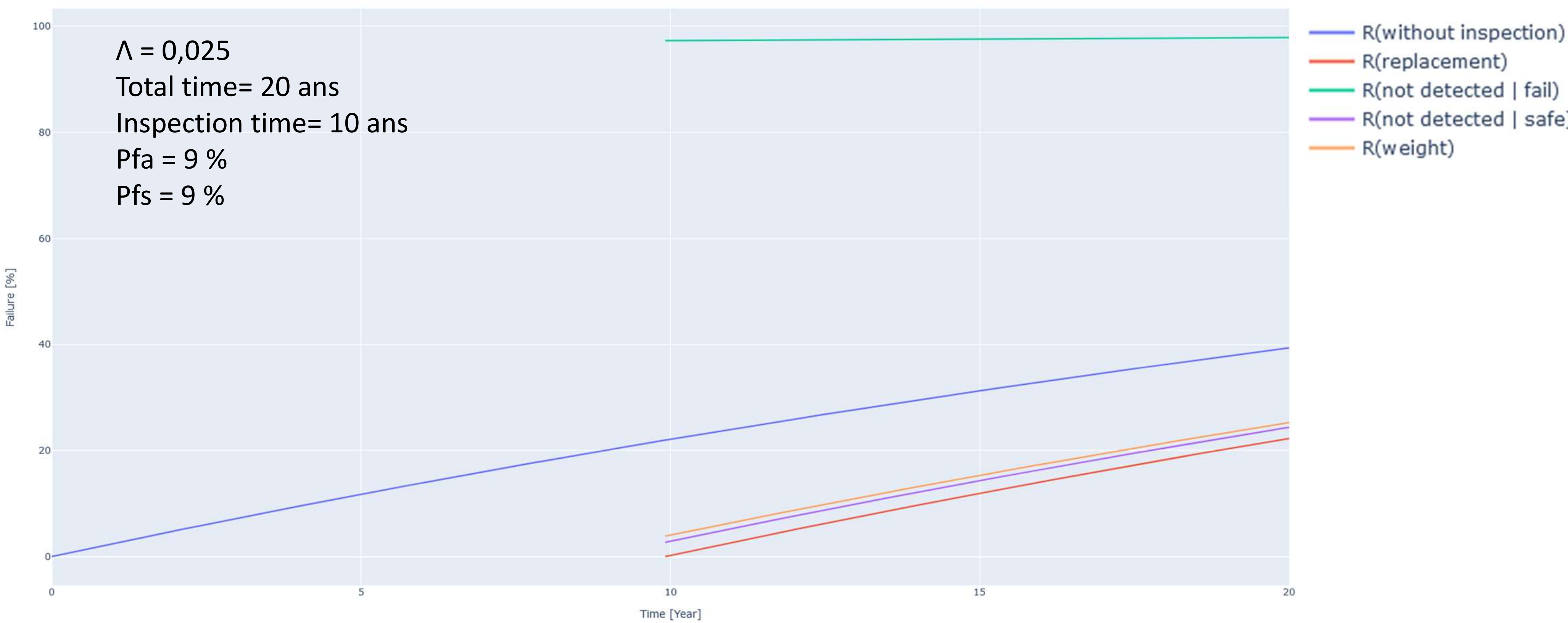
$$Wear\ Out\ Failure = 1 - \exp\left(-\frac{1}{MTTF}\, t\right)$$



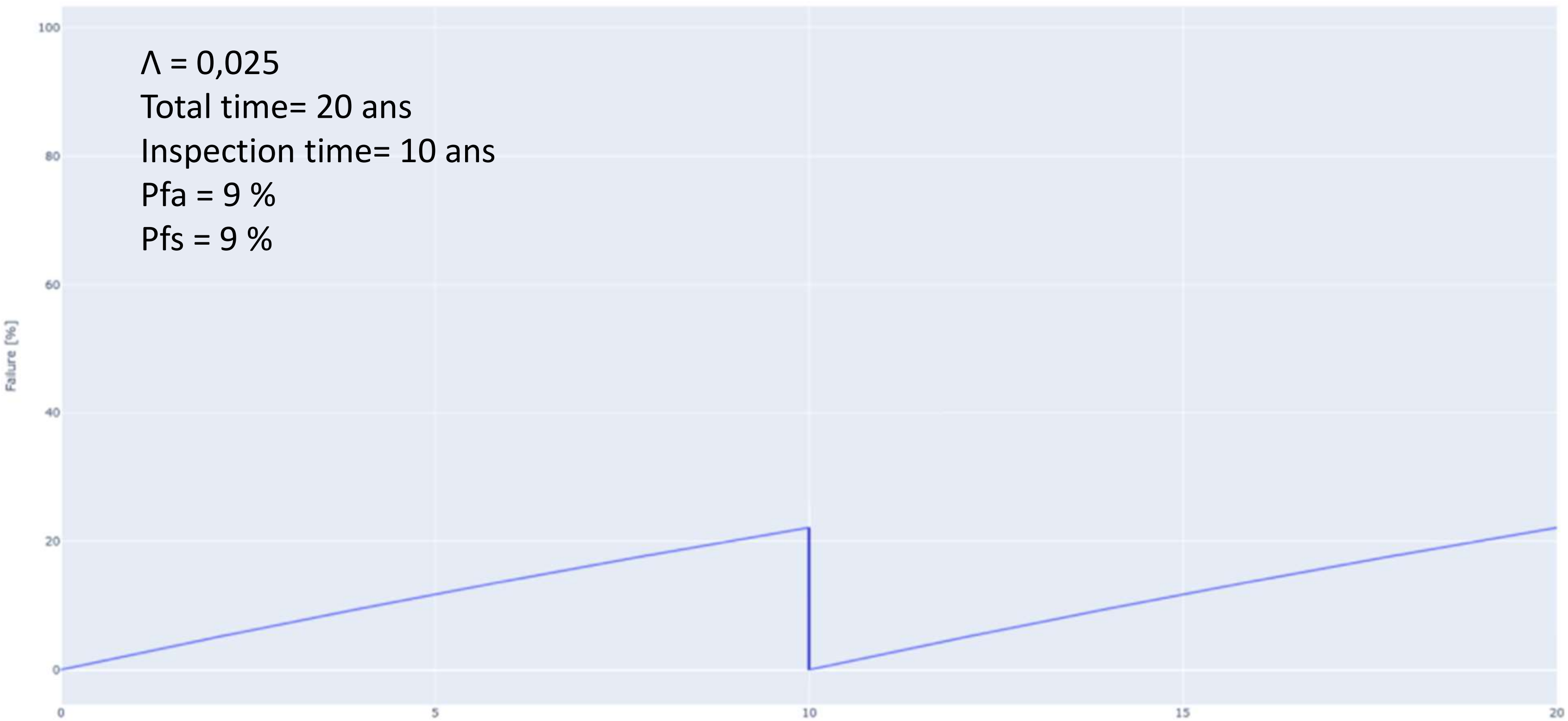
Association of reliability



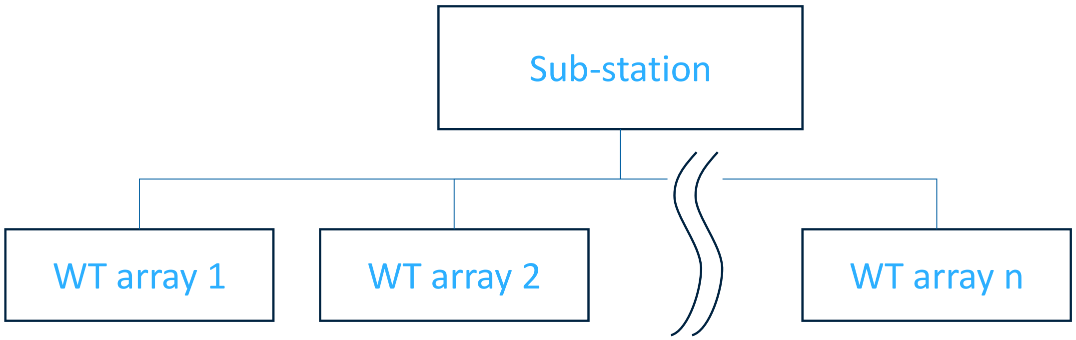
Reliability behavior under Inspection



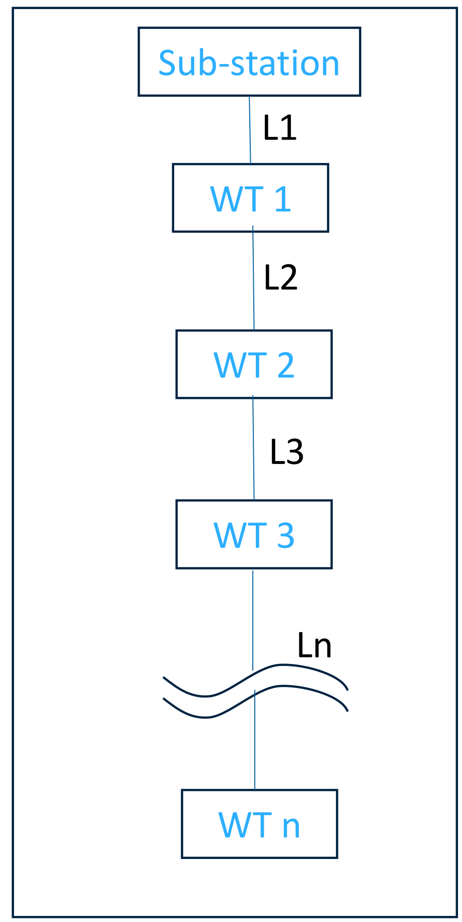
Reliability behavior under Inspection



Inter-array cable reliability



WT array



- From the reliability point of view, the cable length:

$$L_{Cable\ WT_n} = \sum_{i=1}^{n} L_{cable\ WT\ i}$$

- Reliability of L length of cable in series:

$$R_{Array\ cable} = R_{cable\ [\frac{-}{km}]}^{L_{Cable\ WT}}$$

- Reliability of wind turbine and cable in series:

$$R_{WT\ \&\ Cable} = R_{WT} * R_{Cable}$$

Reliability data for wind turbine

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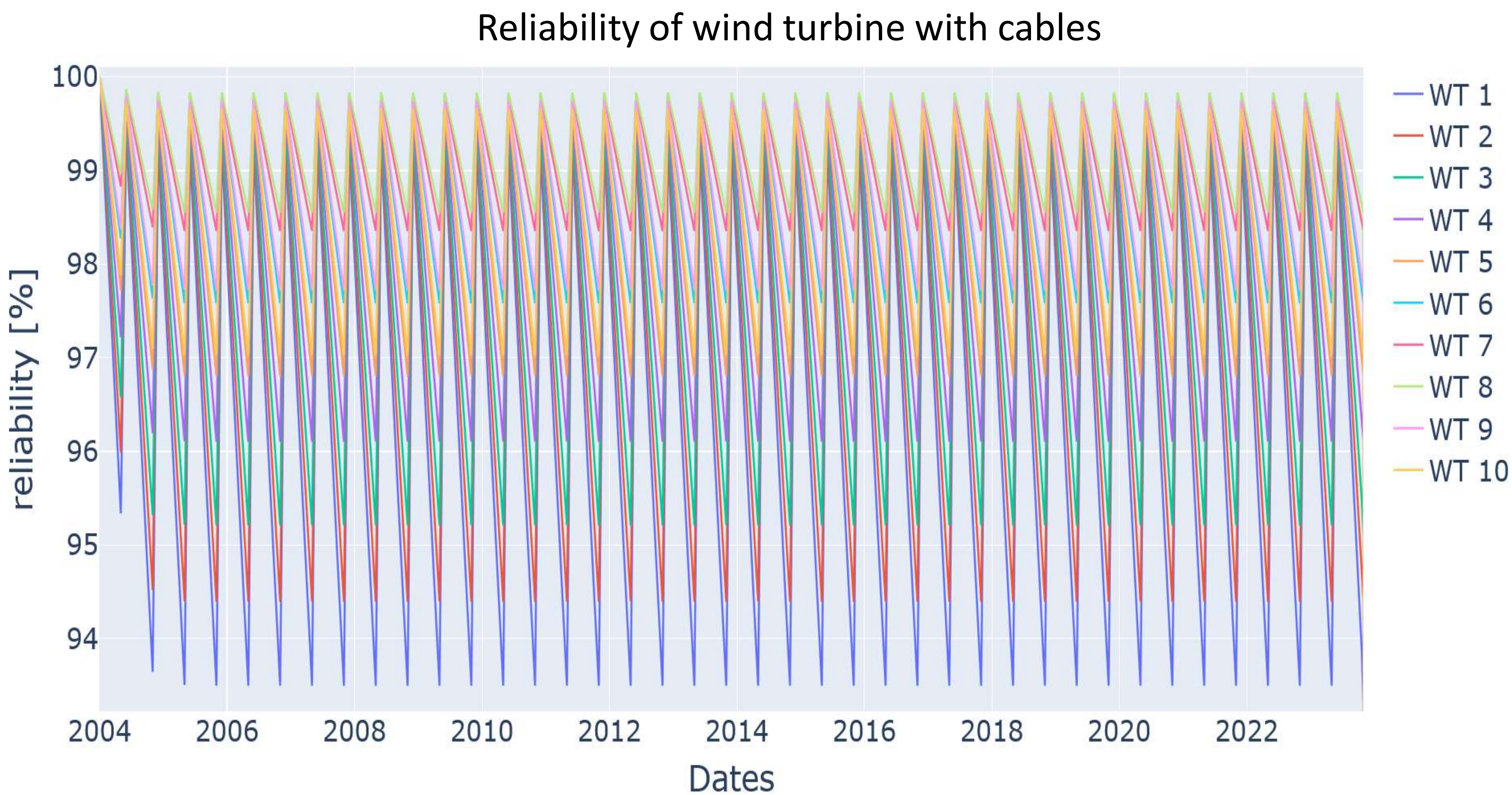
	MR	Mr	mr	No Cost Data	lambda total
Pitch / HYd	0,001	0,179	0,824	0,072	**1,076**
Other Compon	0,001	0,042	0,812	0,15	**1,005**
Generator	0,095	0,321	0,485	0,098	**0,999**
Gearbox	0,154	0,038	0,395	0,046	0,633
Blades	0,001	0,01	0,456	0,053	0,52
Grease / Oil / CoolingLiq	0	0,006	0,407	0,058	0,471
Electrical Components	0,002	0,016	0,358	0,059	0,435
Contacto / Circuit Breaker /Relay	0,002	0,054	0,326	0,048	0,43
Controls	0,001	0,054	0,355	0,018	0,428
Safety	0	0,004	0,373	0,015	0,392
Sensors	0	0,07	0,247	0,029	0,346
Pumps/ Motors	0	0,043	0,278	0,025	0,346
Hub	0,001	0,038	0,182	0,014	0,235
Heaters / Coolers	0	0,007	0,19	0,016	0,213
Yaw System	0,001	0,006	0,162	0,02	0,189
Tower / Foundation	0	0,089	0,092	0,004	0,185
Power Supply / Converte	0,005	0,081	0,076	0,018	0,18
Service Items	0	0,001	0,108	0,016	0,125
Transfor mer	0,001	0,003	0,052	0,009	0,065

Several scientific articles provide reliability data regarding wind turbines. For this study, we utilized the data presented in the work of Carroll et al. [3]. This article offers comprehensive insights into the failure rates and maintenance requirements of wind turbines, making it a valuable resource for modeling and optimization in the field of wind energy. By leveraging these detailed findings, our analysis aims to enhance the accuracy and robustness of reliability assessments for wind farm operations.

[3] J. Carroll, A. McDonald, et D. McMillan, « Failure rate, repair time and unscheduled O&M cost analysis of offshore wind turbines », Wind Energy, vol. 19, no 6, p. 1107-1119, juin 2016, doi: 10.1002/we.1887.

Reliability results on studied wind turbine



Validating resources estimation methodology

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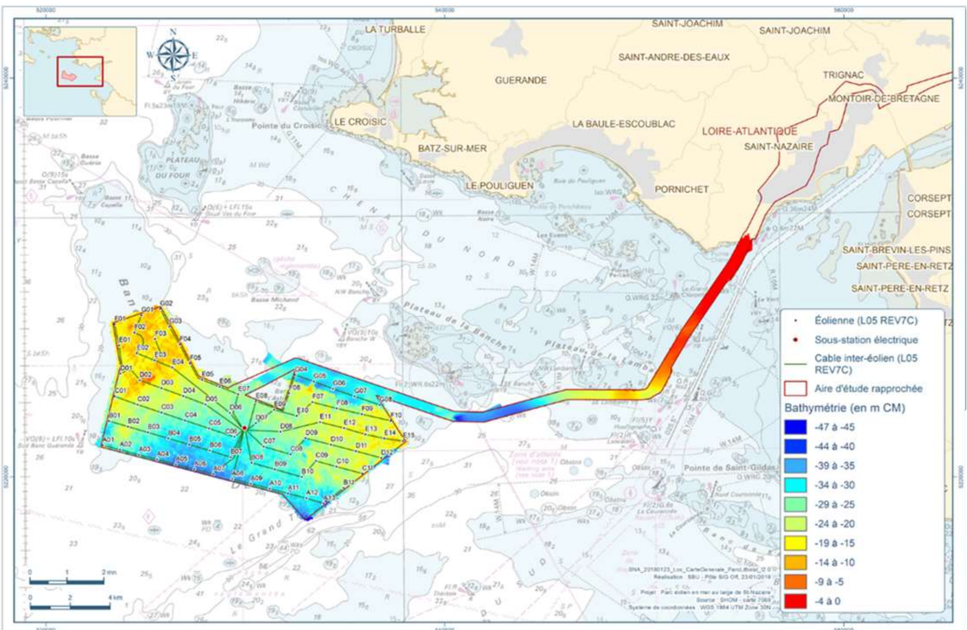
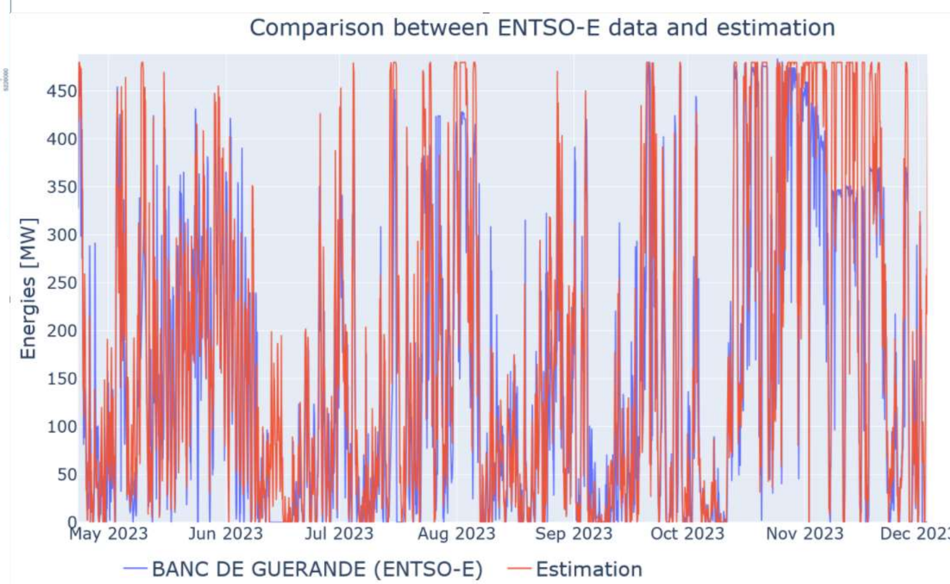


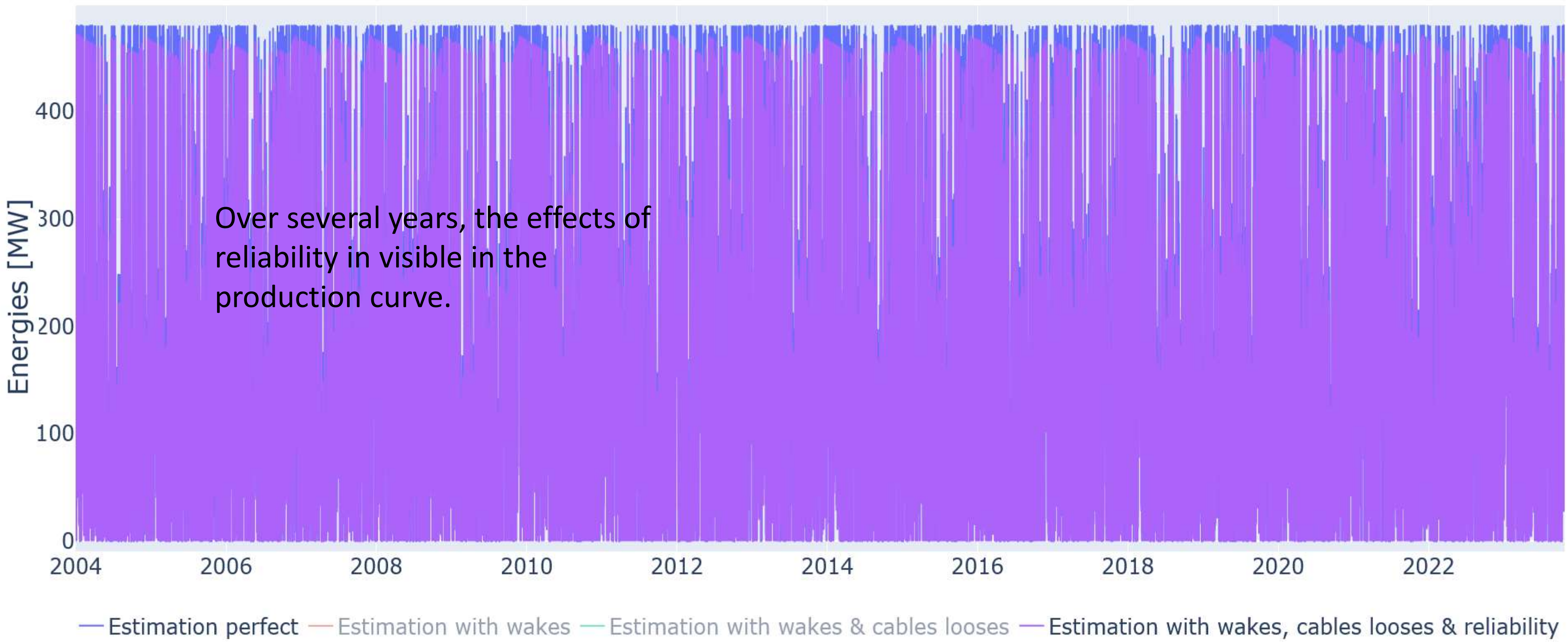
We accurately capture the production trends of a wind farm.

Although a global overestimation of the resource by approximately 10% can be observed. This overestimation may be due to several factors:

- The quality of the wind data,
- The lack of consideration for the performance efficiencies of various converters,
- A discrepancy between the power curves of actual machines (Haliade 150 6MW) and the NREL 6MW.

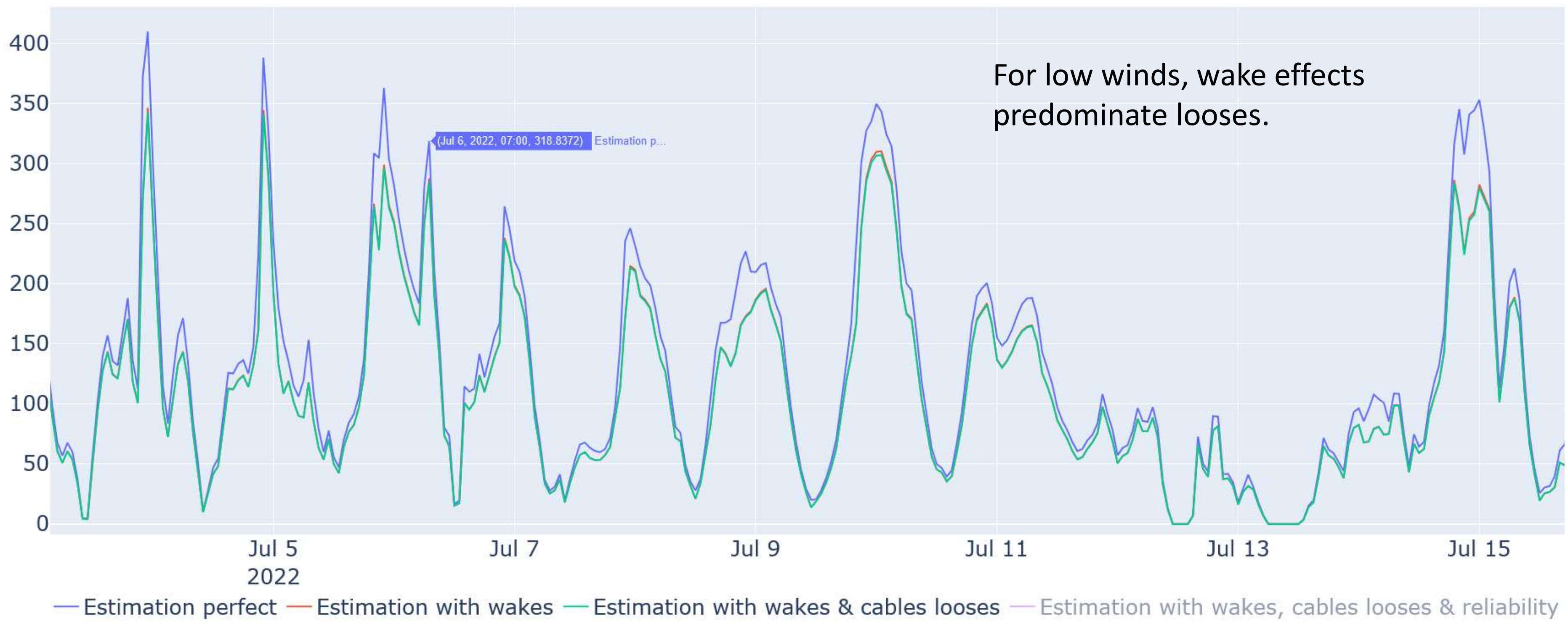


Impact of losses effects

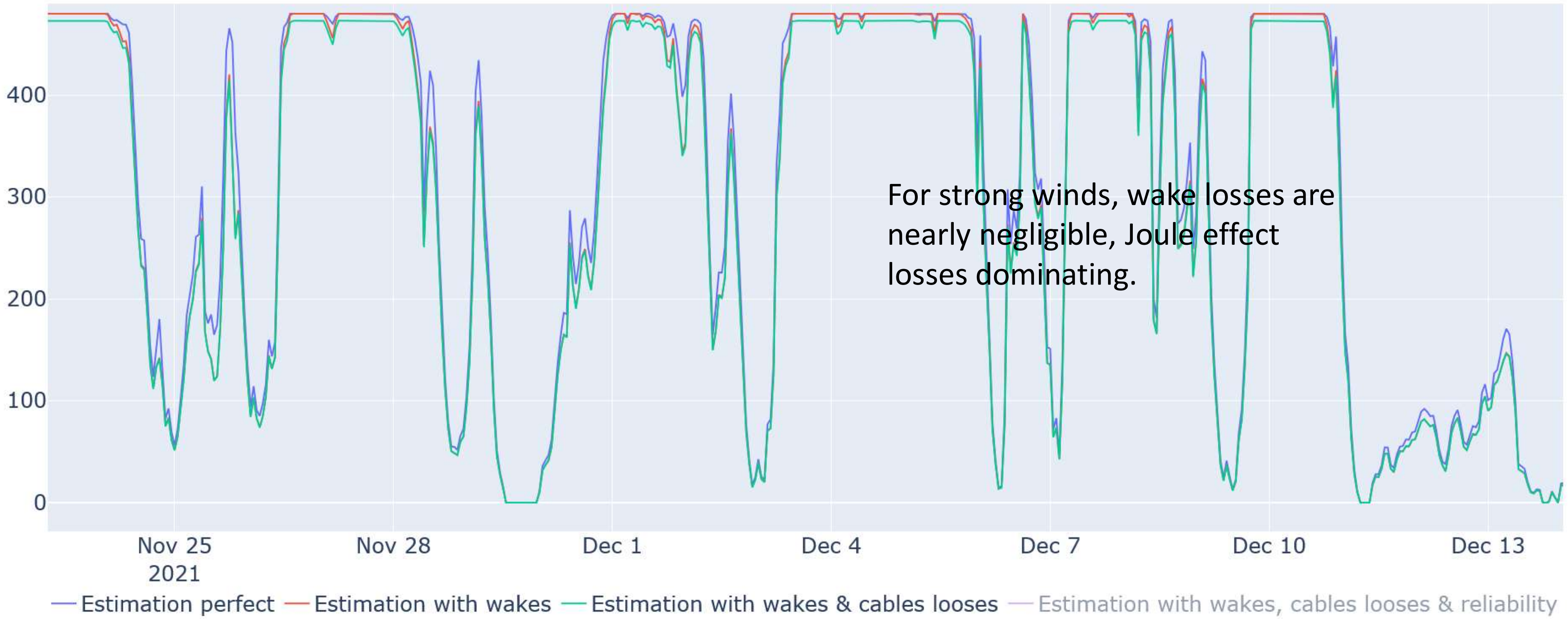


Over several years, the effects of reliability in visible in the production curve.

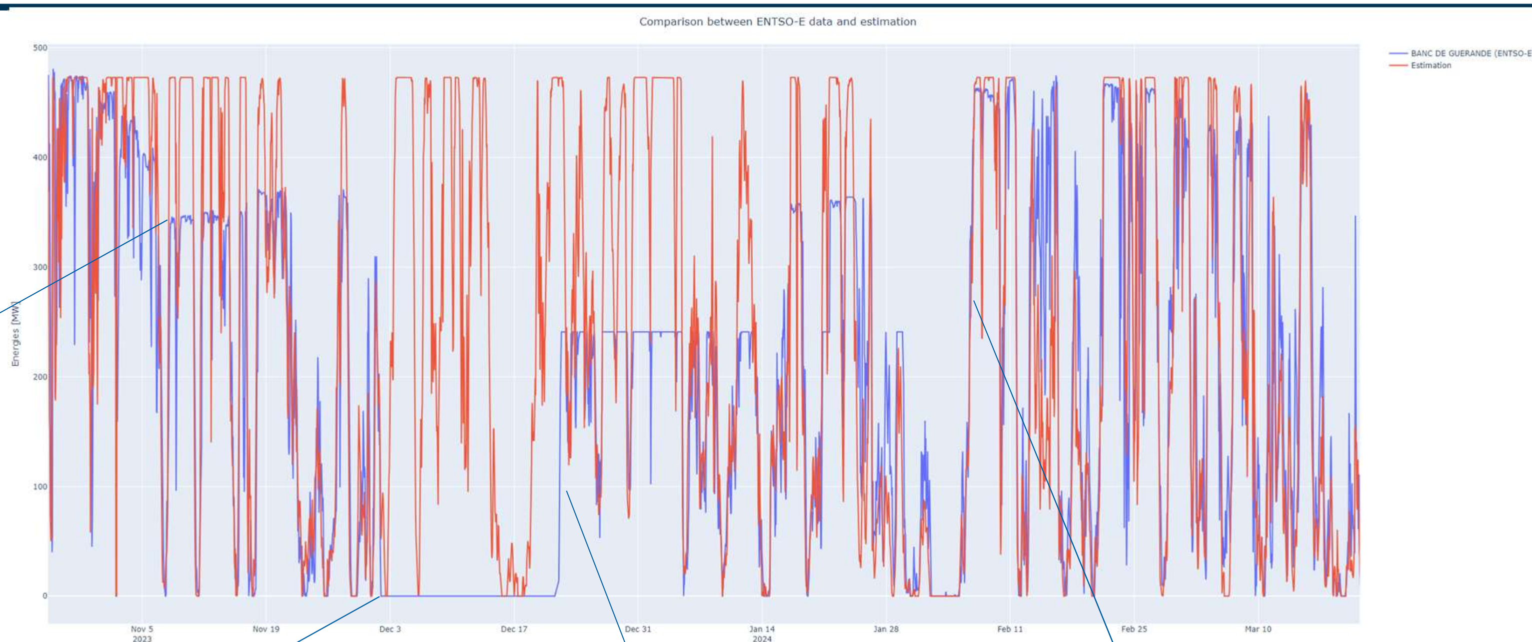
Impact of losses effects



Impact of losses effects



More about ENTSO-E data



Stating power derating of the sub-station

Shutdown of the all sub-station

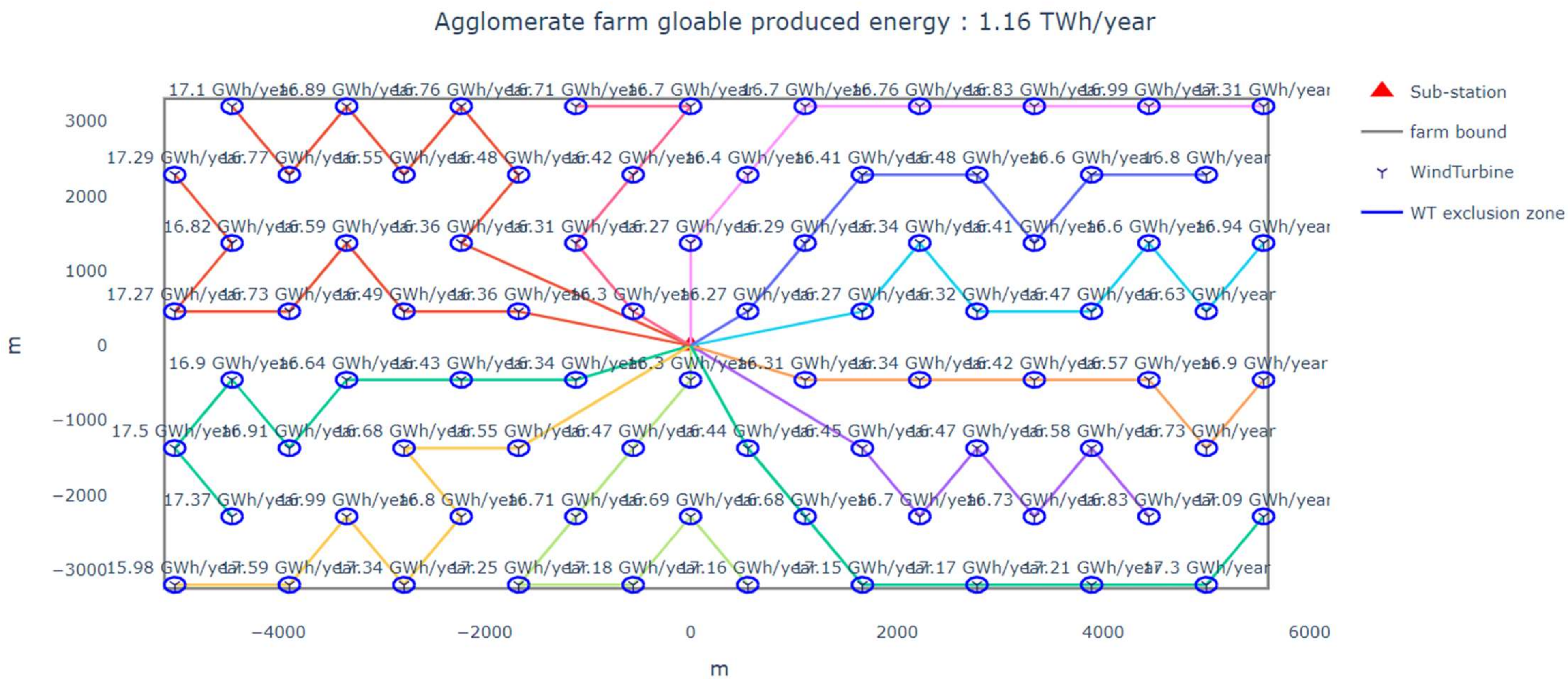
restart 1 of 2 export line

restart both export line

Optimization methodology

- In this project, our objective is to develop an optimization solution that is as versatile as possible. The first step involves defining the optimization indicators that we aim to use:
  - **Production**
  - **Reliability**
  - **Cost** (OPEX + CAPEX)
  - **Levelized Cost of Energy (LCOE)**
- Subsequently, we explored various categories of optimization algorithms that could potentially yield effective results for a problem as complex as ours. Among the approaches we tested were:
  - **PSO (Particle Swarm Optimization)**
  - **ABC (Artificial Bee Colony)**
  - **CCMO with GA (Constrained Cooperative Multiobjective Optimization combined with Genetic Algorithm)**
- However, the results obtained from these methods have been inconclusive. None of them consistently outperformed a straightforward arrangement of points in a square or staggered grid pattern. Furthermore, no clear or meaningful structure emerged from these optimization techniques. It is also worth noting that the search spaces for these algorithms are inherently more suited to rectangular configurations, which may limit their ability to adapt to alternative layouts.

Preliminary Optimization Results



Preliminary Optimization Results

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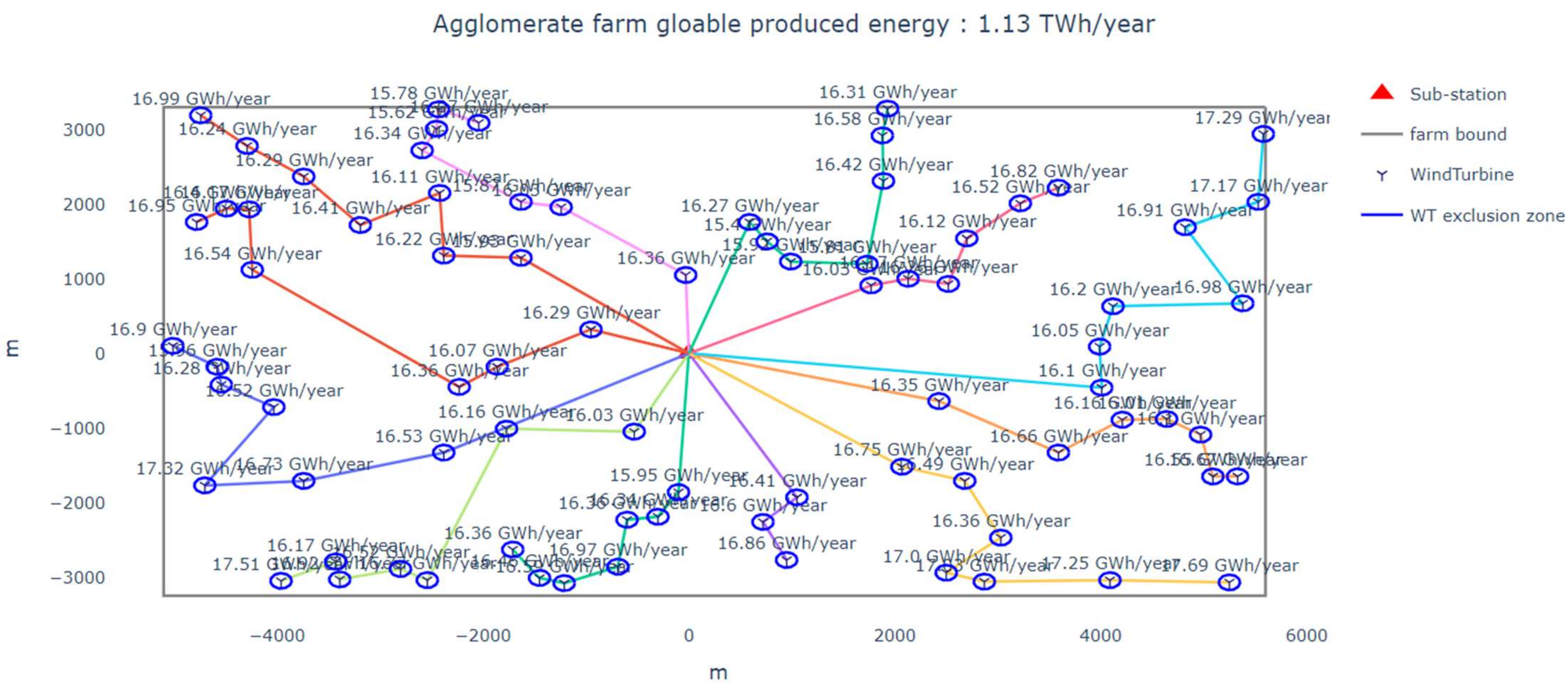

Conclusion

- In this project, we have implemented all the necessary components to evaluate wind energy potential while considering:
  - **Site-specific characteristics**: weather conditions, location, and geography.
  - **Interactions between turbines**: compliance with exclusion zones, wake effects, and energy losses in cables.
  - **The integration of reliability as an optimization metric.**
- However, as we have observed, the tools required to achieve effective optimization are not yet fully functional and need further refinement. Key areas for improvement include:
  - Defining wind farm boundaries in configurations beyond simple rectangular shapes.
  - Selecting an optimizer better suited to address the specific challenges of this problem.
  - Integrating broader constraints such as ecological considerations (e.g., wildlife) and socio-economic factors (e.g., fishing activities).
- Despite these challenges, this project provides a solid foundation for further research and development in wind farm optimization, paving the way for solutions that are both technically sound and environmentally sustainable.