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Opportunistic Maintenance for Offshore Wind Farms

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Introduction

- Wind energy is set to supply **35%** of the nation's electricity by **2050**. As of 2019, this percentage stands at **7.3%**.
- Operations & Maintenance (O&M) costs are a major contributor to wind's cost of energy, and hence, its economic outlook (~**30%** of total wind energy cost).
- The O&M costs are even higher for offshore wind due to:
  1. **Limited accessibility** (i.e. dozens of miles off the shores).
  2. **High production losses** (i.e. 12MW turbines).
  3. **Safety considerations** (i.e. harsh wind & wave conditions).
- The industrial practice for O&M planning is mostly reactive, while most research studies are agnostic to offshore settings.
- We propose an offshore-specific **opportunistic maintenance scheduling strategy** based on mixed integer linear programming (**MILP**) which minimizes the total maintenance costs by:
  1. Grouping maintenance tasks whenever possible.
  2. Scheduling maintenances during low-wind periods.
  3. Considering site accessibility and safety considerations.

An Insight to the Mathematical Model

- The time framework is split into two horizons:
- **Short-term horizon** (STH): hourly intervals $t = 1, \dots, 24$h ahead
- **Long-term horizon** (LTH): daily intervals $d = 2, \dots, 15$d ahead
- Profits are combined into a single objective function:

$$\max \underset{\substack{\swarrow \\ \text{Short-term profit}}}{s} + \sum_{d} \underset{\substack{\searrow \\ \text{Long-term profit}}}{l^{d}}$$

- **Short-term profits** (for the day-ahead planning):

$$s = \sum_{i} \left[\sum_{t} \left(\underbrace{\Pi p^{t,i}}_{\text{Revenue}} - \underbrace{K m^{t,i} - \Phi n^{t,i}}_{\text{Maintenance costs}} - \underbrace{\Psi x^{t,i}}_{\text{Crew hourly payment}} \right) \right] - \underbrace{\Xi v}_{\text{Vessel rental}} - \underbrace{Q q}_{\text{Overtime pay}}$$

- **Long-term profits** (for long-term planning):

$$l^{d} = \sum_{i} \left(\underbrace{\Pi p_{L}^{d,i}}_{\text{Revenue}} - \underbrace{K m_{L}^{d,i} - \Phi n_{L}^{d,i}}_{\text{Maintenance costs}} - \underbrace{\Psi \tau \left(m_{L}^{d,i} + n_{L}^{d,i} \right)}_{\text{Crew hourly payment}} \right) - \underbrace{\Xi v_{L}^{d}}_{\text{Vessel rental}}$$

- **Other constraints include:**
- Crew access.
- Turbine availability & power output.
- Maintenance actions.
- Residual life estimates (RLEs).

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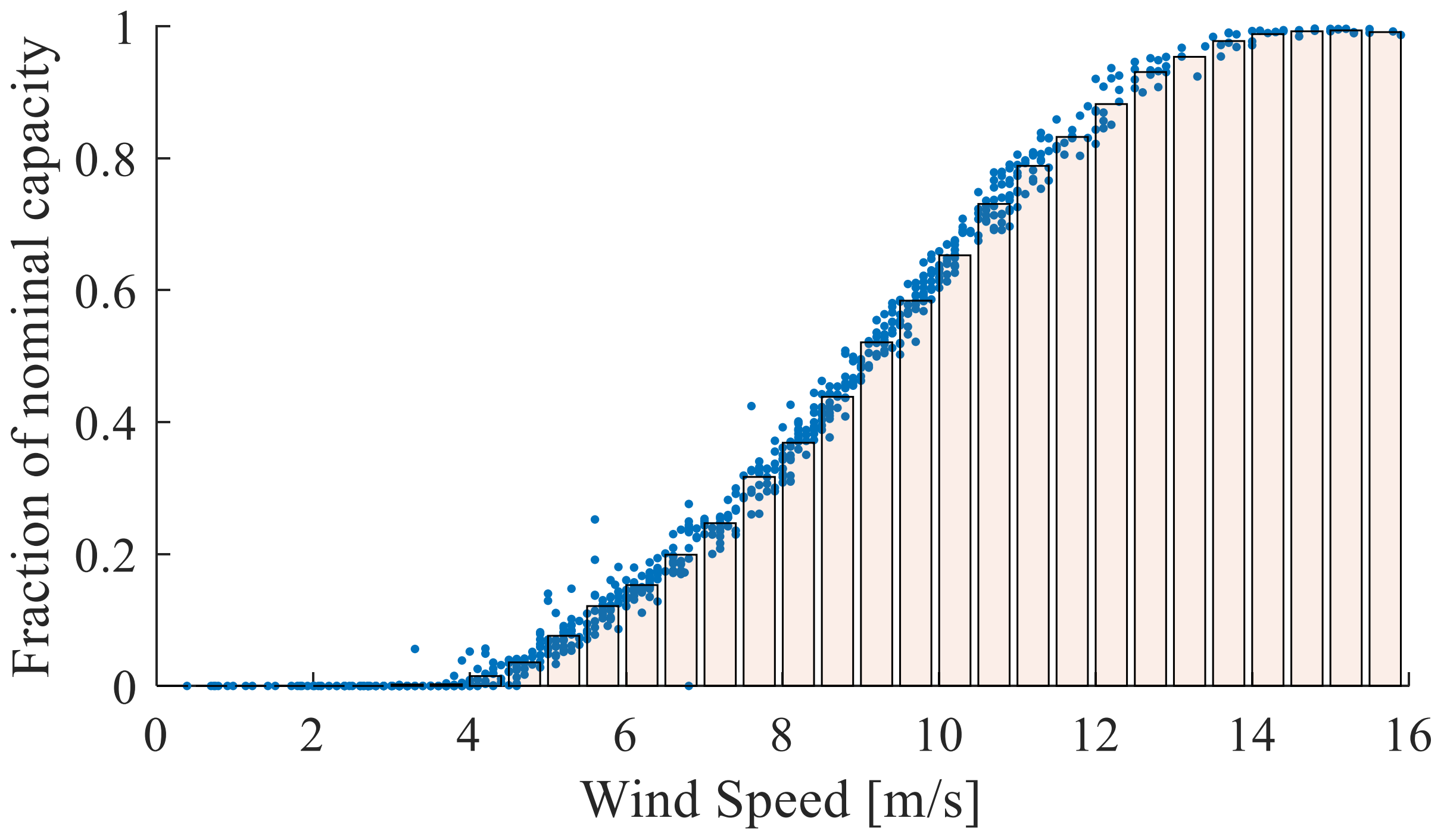
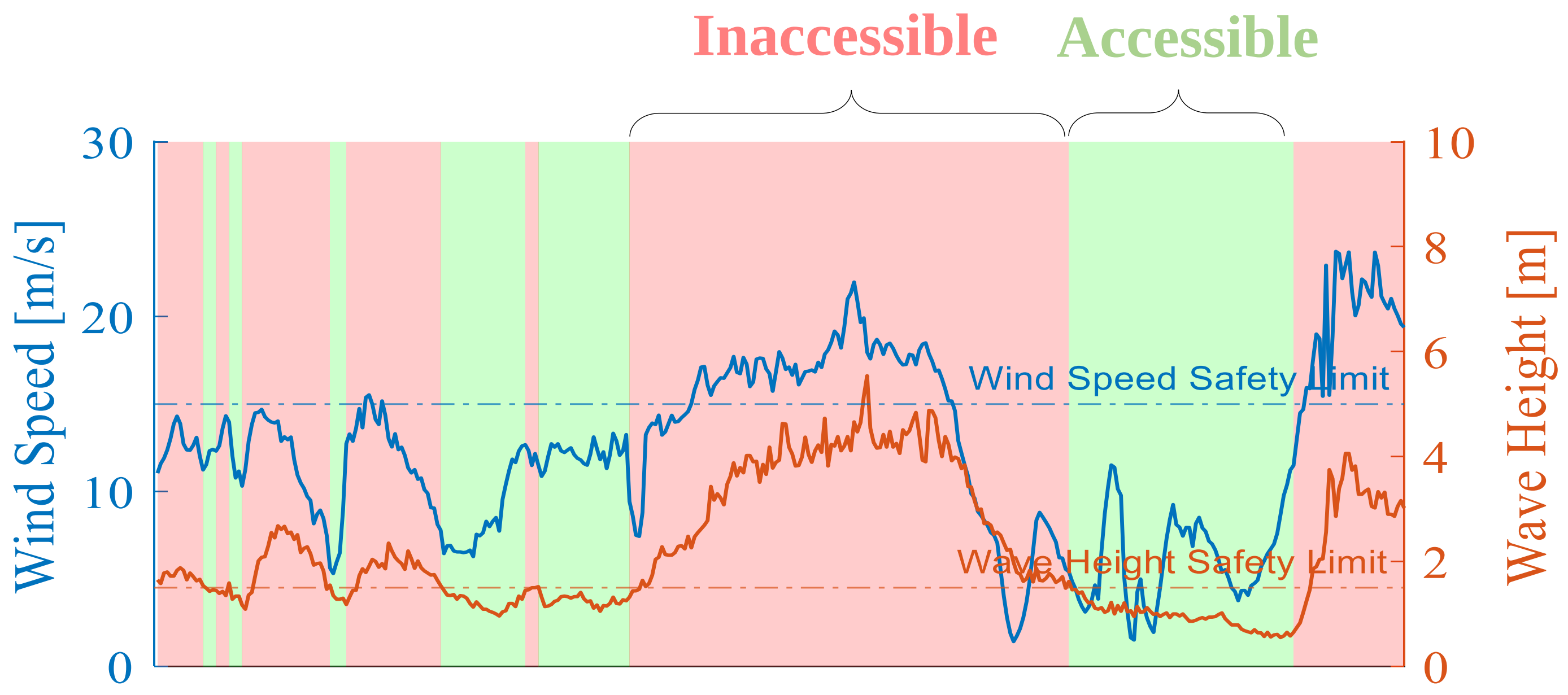
Case Study

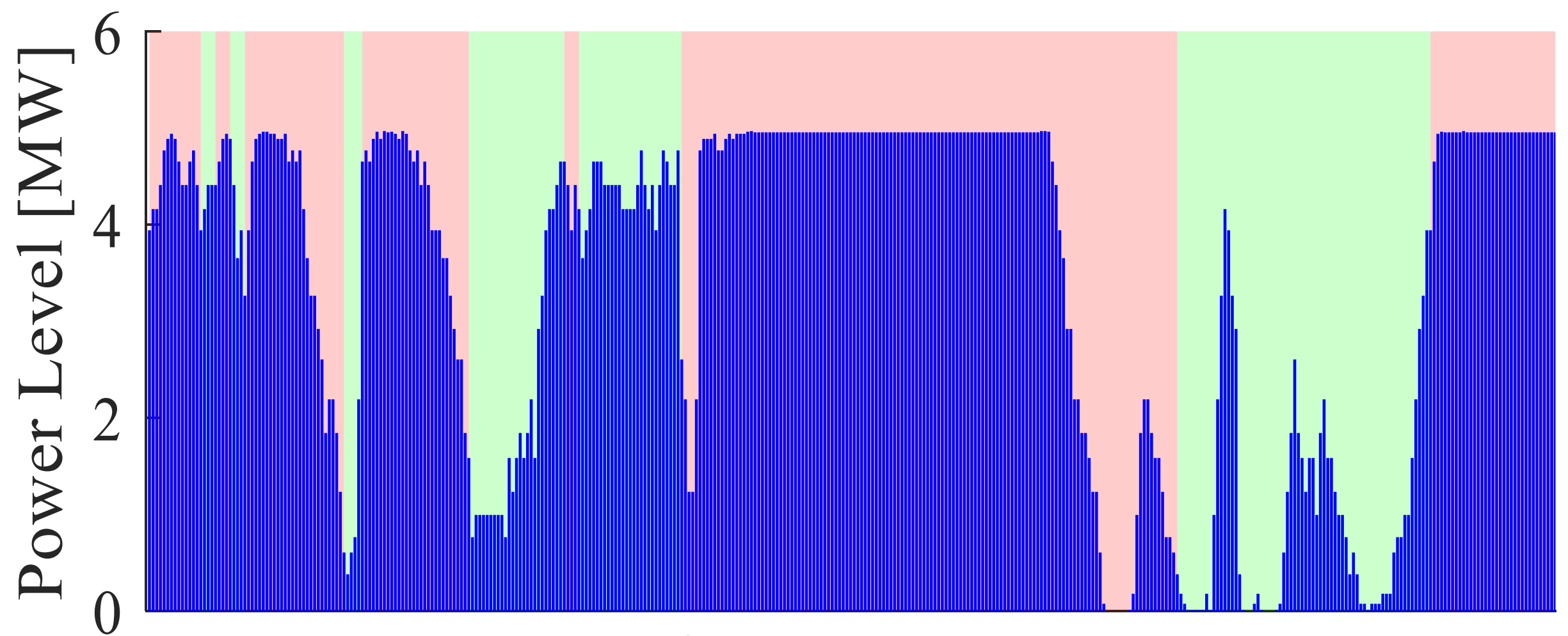
- Assume **10** turbines with **5 MW** capacity per turbine.
- Wind speed and wave height is obtained via NYSERDA's deployed Buoys at a potential wind farm site off New York.
- Power data is obtained from an operational wind farm in the US, as a **fraction of the nominal capacity** of the wind turbine.
- Wind and RLE forecasts are assumed to be available.
- Wind power curves are estimated using the method of bins to calculate the power output as a function of wind speed.



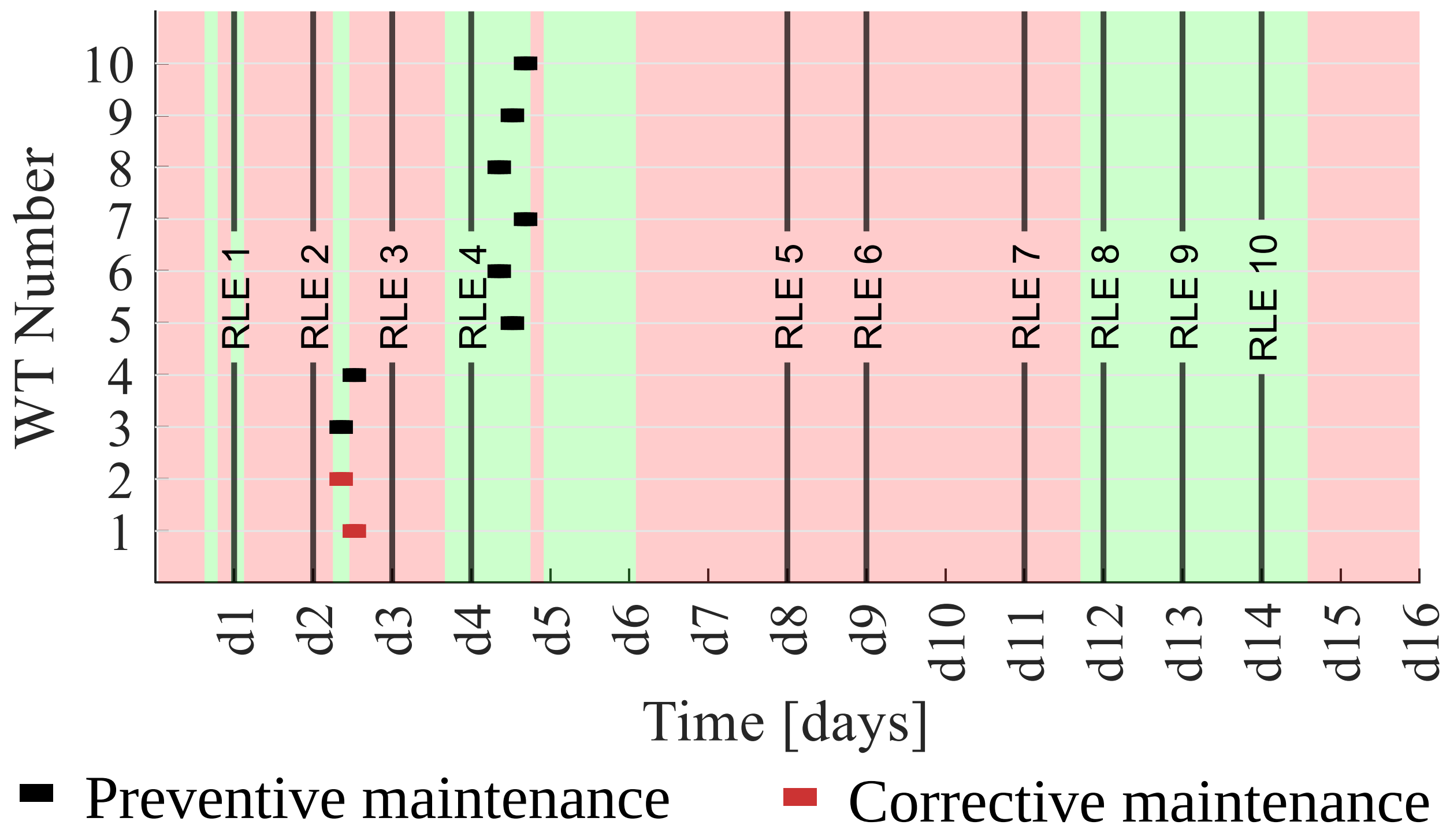
- Crew access on offshore wind turbines is performed with crew transport vessels (CTVs); access is restricted when:
  1. Wave height (Average) > 1.5 m (for a medium-sized CTV).
  2. Wind speed (Average) > 15 m/s (for the turbine's nacelle).



Wind speed (left) & wave height (right) profile for our case study; access is restricted when either attribute exceeds its safety limit



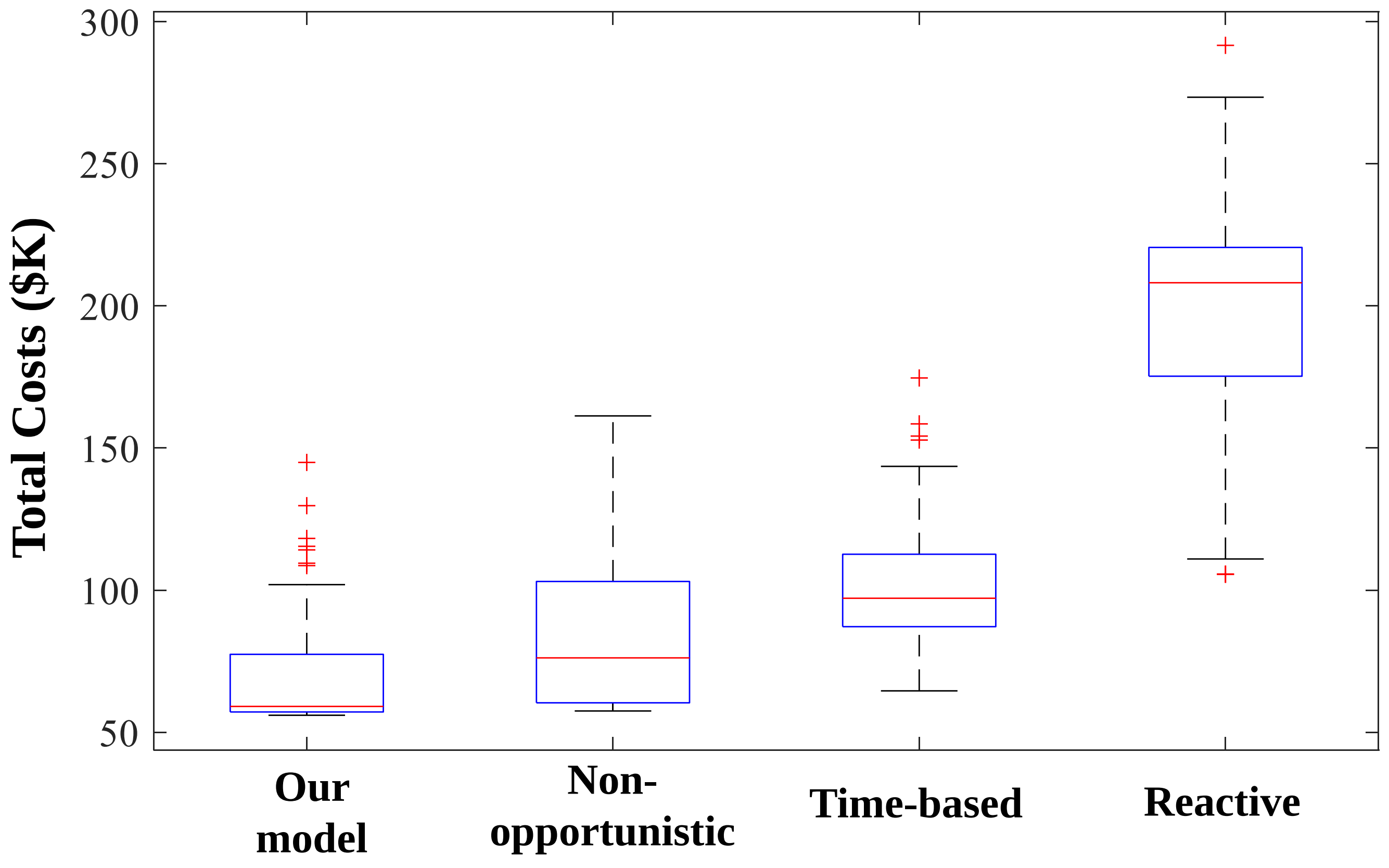
The power output profile by each turbine in this case study

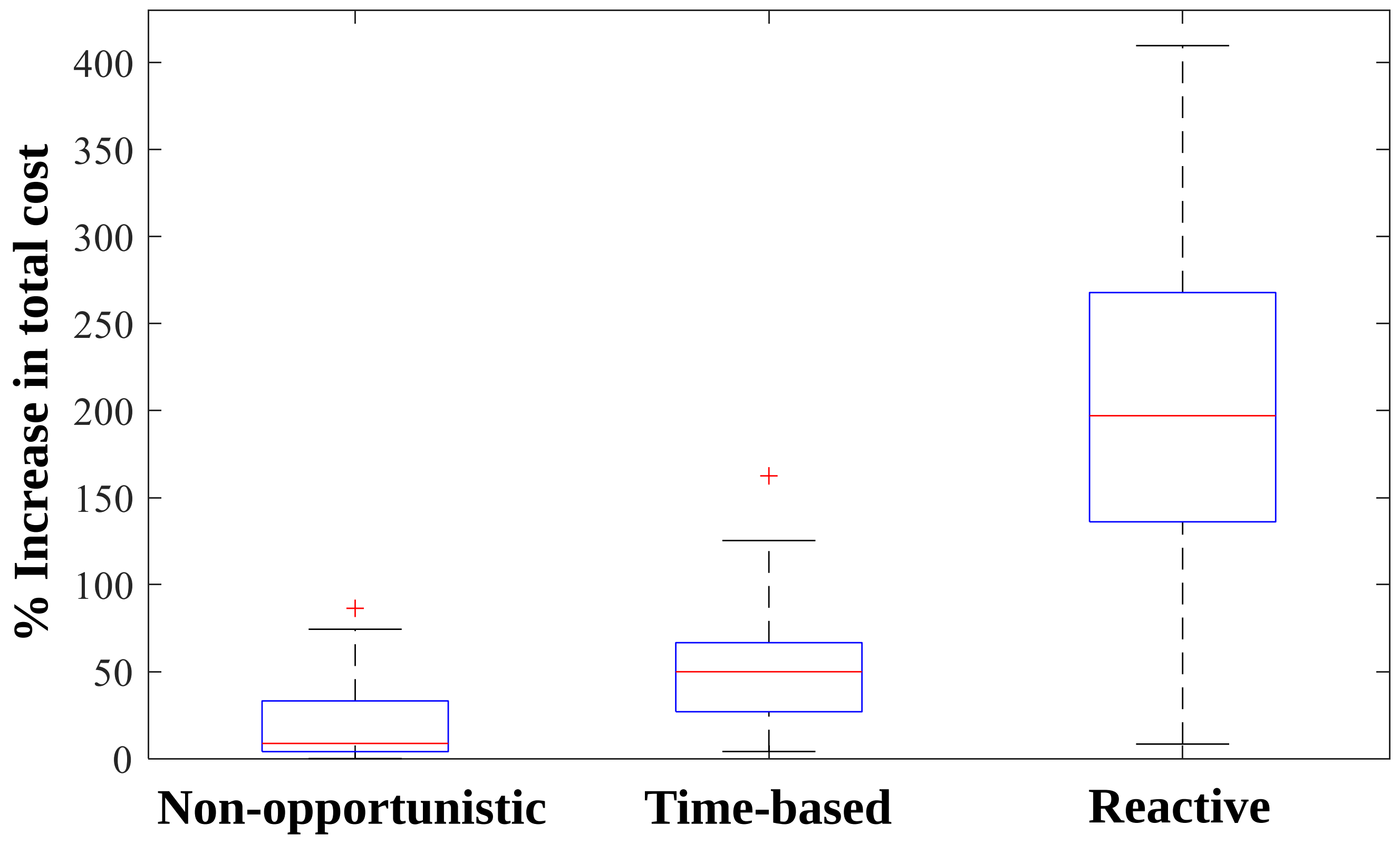


The hourly schedule for all 16 days; result contains two corrective maintenances as they were performed after their RLEs, due to access restriction

Results

- The optimization is performed using GAMS on a standard laptop by IBM's CPLEX solver; the average solution time < **30 sec** for an optimality gap < **0.1%**.
- Our opportunistic model is solved for **80** different weather profiles, and compared to **3** other strategies:
  1. **Non-opportunistic**: no accessibility, no vessel dispatch costs.
  2. **Time-based**: maintenance performed at or near the RLE.
  3. **Reactive**: corrective maintenance only.





- The benchmarking shows that a non-opportunistic strategy is, on average, ~**20%** more expensive.
- The corresponding percent increase in cost for time-based and reactive strategies are ~**50%** and **200%**, respectively.

Conclusions & Contribution

- From the comparison, it seems that our model yields the best result in all scenarios.
- The model presented is **efficient** both cost-wise and computation-wise.
- Study highlights the **importance** of employing our **opportunistic strategy**, compared to other popular strategies followed in the literature and practice of offshore wind energy.

References

- For a full list of references please contact: petros.papadopoulos@rutgers.edu