Estimating Maintenance Costs of Offshore Electrical Substations under Uncertainty

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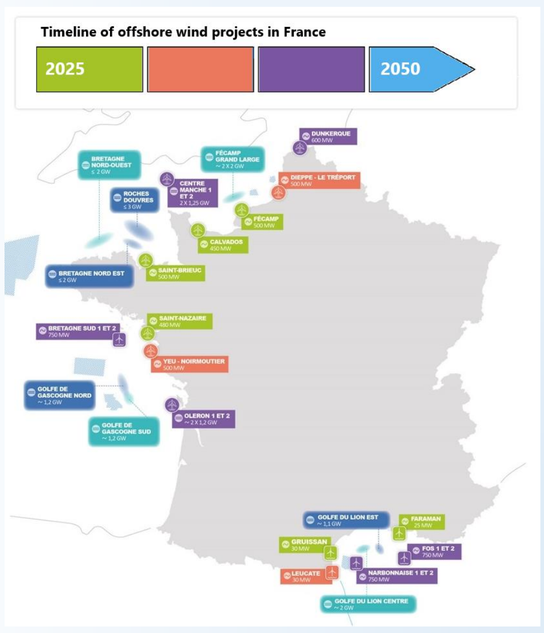
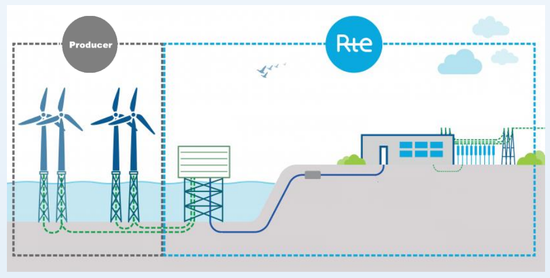
Context

Ambitious offshore wind development plan

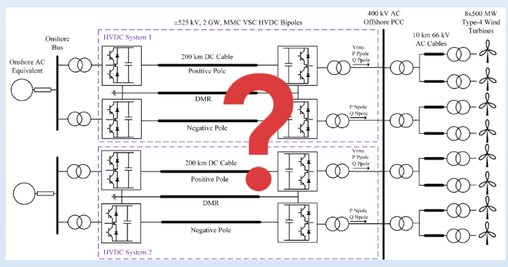


Grid connection

RTE owns and maintains the substation



We want to estimate the costs associated with strategic choices, such as the design of the substation



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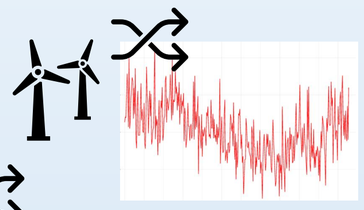
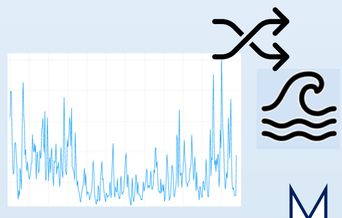
Estimating costs is challenging

Substations are far from the coast

Random production and wave height

Compensations proportional to production above evacuation capacity





Accessibility is uncertain

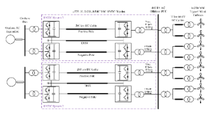
We rely on stochastic optimization

The model in brief: **Optimize maintenance operations under uncertainty to estimate the penalties incurred by strategic choices.**

Key aspects of modeling

Strategic choices

Substation design



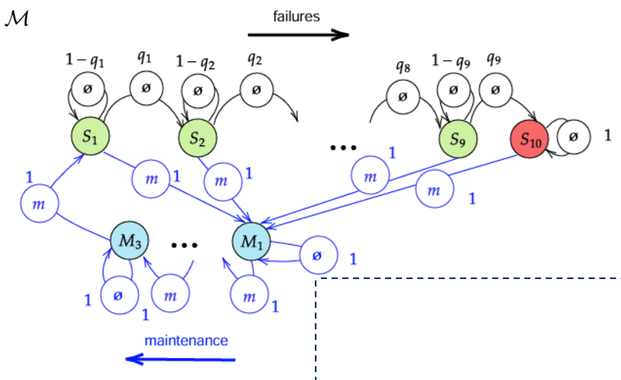
Inventory management

Transport

Strategic choices are represented in the MDP.

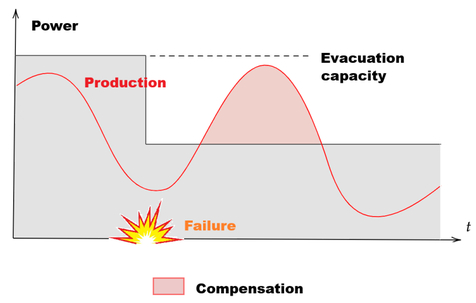
Markov Decision Process (MDP)

- **state** $x \in \mathcal{X}$
  - ➥ level of degradation S_i
  - ➥ ongoing maintenance operations M_i
- **action**
  - ➥ wait Ø or do maintenance $m \in \mathcal{M}$
- **transition probabilities** $\mathrm{P}^m_{xx\prime}$
  - ➥ failures / maintenances
- **reward** $C(x)$



Producer compensation

Objective function: minimize penalties



$$C(\underbrace{w}_{\text{weather}}, \underbrace{x}_{\text{state}}) = (\text{Production}(w) - \text{Capacity}(x))^+$$

Value function associated with the strategic problem

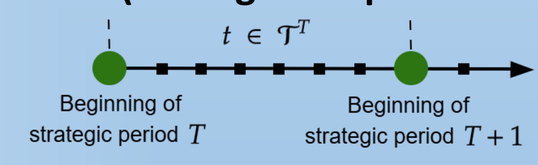
$$V_T(x_0) = \min_{u_{[\mathcal{T}^T]} \in \mathcal{U}_T} \frac{1}{|\mathcal{S}_T|} \sum_{s \in \mathcal{S}_T} \mathbb{E}_{\mathbb{P}} \left[\sum_{t \in \mathcal{T}^T} C(w_t^s, \boldsymbol{X}_t^s) + V_{T+1}(\boldsymbol{X}^s_{|\mathcal{T}^T|}) \right]$$

s.t. $\mathbb{P}(\boldsymbol{X}^s_{t+1} = x\prime | \boldsymbol{X}^s_t = x, m^s_t = m) = \mathrm{P}^m_{xx\prime}$

$\boldsymbol{X}^s_0 = x_0$

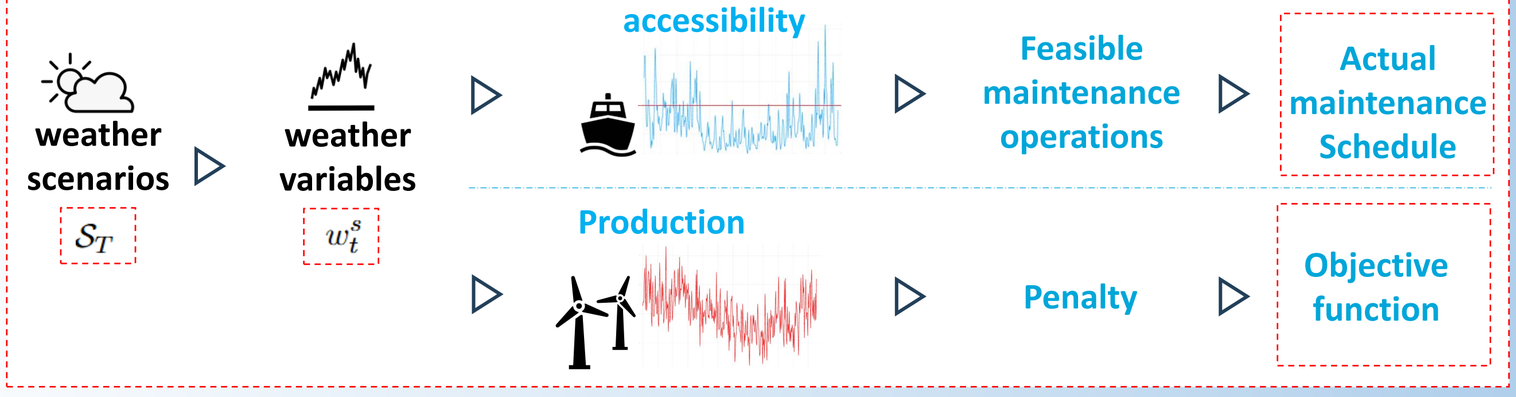
$m^s_{[\mathcal{T}^T]} = \text{ActualSchedule}(u_{[\mathcal{T}^T]}, w^s_{[\mathcal{T}^T]})$

Multihorizon stochastic optimization (strategic vs operational)



- u_t : Maintenance scheduling decisions
  - ⇨ taken every 2 months (strategic problem).
- m^s_t : Actual schedule in weather scenario $s \in \mathcal{S}_T$
  - ⇨ time step of 1 day.

Uncertainties



(Future work)

Lack of offshore reliability data

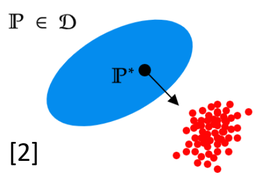
⇩

Model uncertainty

⇩

Distributionally Robust Optimization [3,4]

$$\inf_{u} \sup_{\mathbb{P} \in \mathcal{D}} \mathbb{E}_{\mathbb{P}} [C(\boldsymbol{w}, \boldsymbol{X})]$$



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References

- [1] : Alex Alefragkis and Sertkan Kabul, Next Generation Offshore Grid Connection Systems: TenneT's 2 GW Standard. Electra n.321, April 2022
- [2] : Chao Shang et al., Distributionally robust optimization for planning and scheduling under uncertainty. Computers & Chemical Engineering, Volume 110, 2018, Pages 53-68, ISSN 0098-1354
- [3] : Bart PG Van Parys et al., From data to decisions : Distributionally robust optimization is optimal. Management Science, 67(6) :3387–3402, 2021
- [4] : Vineet Goyal et al., Robust Markov Decision Process: Beyond Rectangularity. Mathematics of Operations Research 48(1):203-226, 2022