On location and vessel fleet composition for offshore wind farm maintenance

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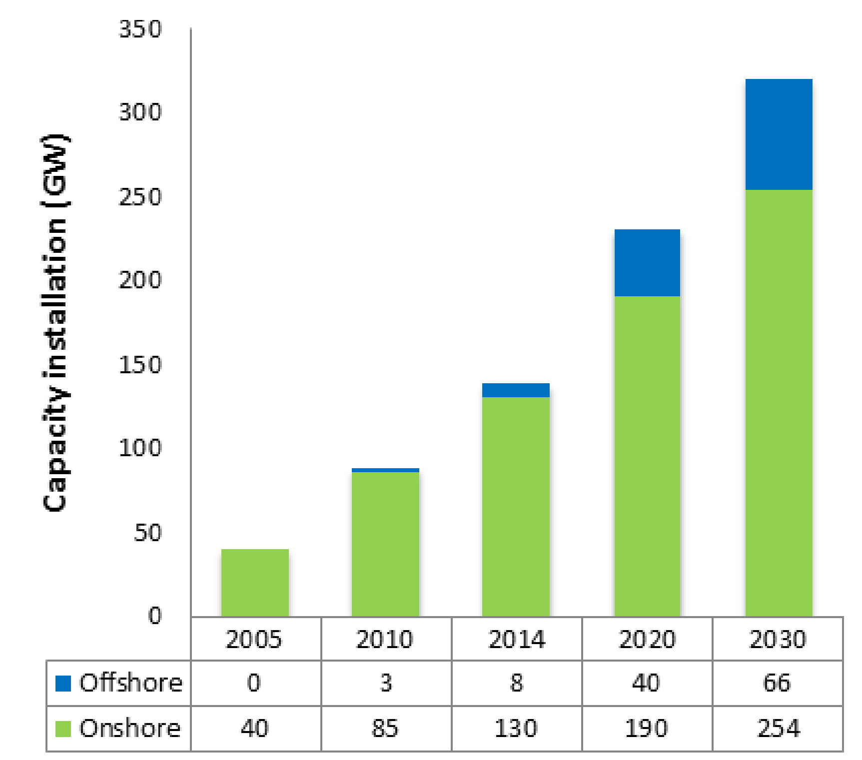
Investigating wind farm operations

Numbers please

- Maintenance scheduling in off-shore wind farms, cooperation with Norway



Total capacity of EU wind energy

Spain:

electric 40% renewable

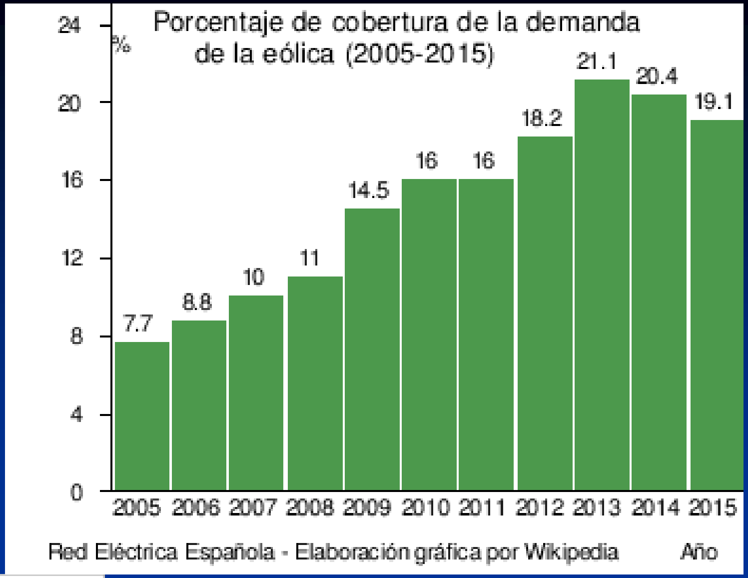
Energy 16% renewable

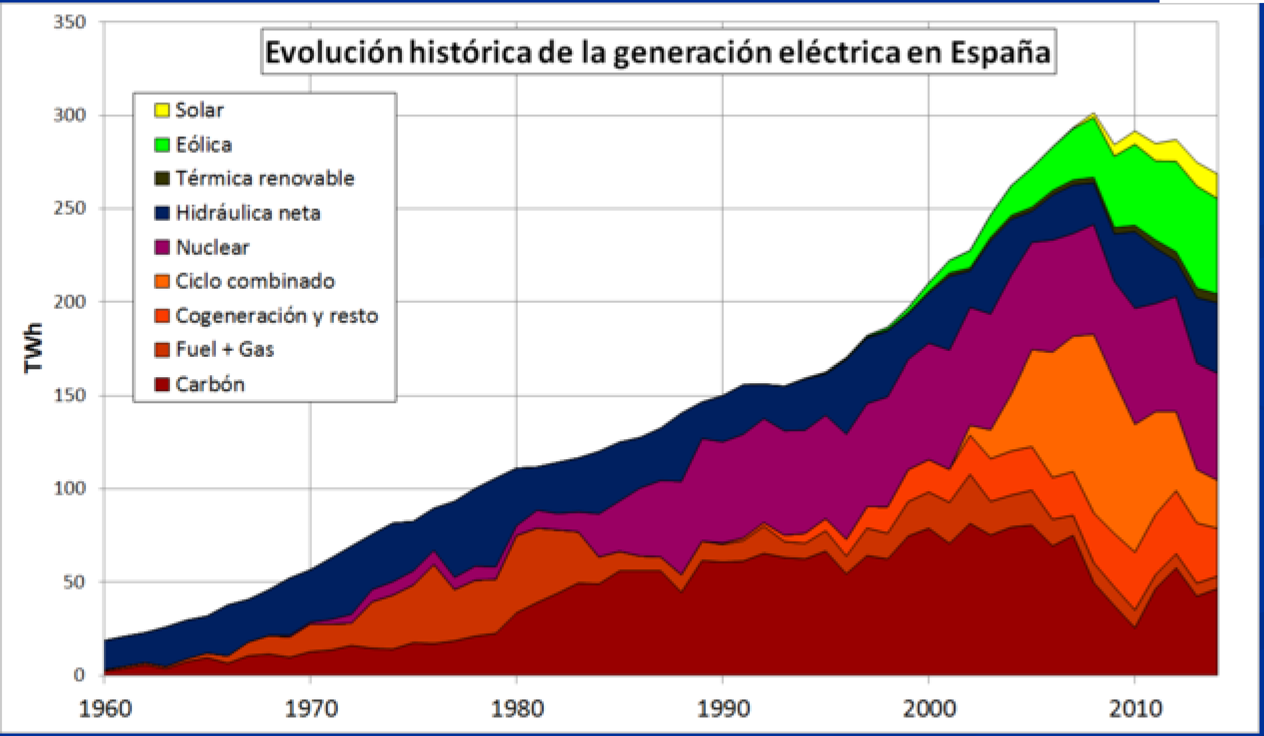
2020 → 20%

2nd in eolic

2013-2015 how many

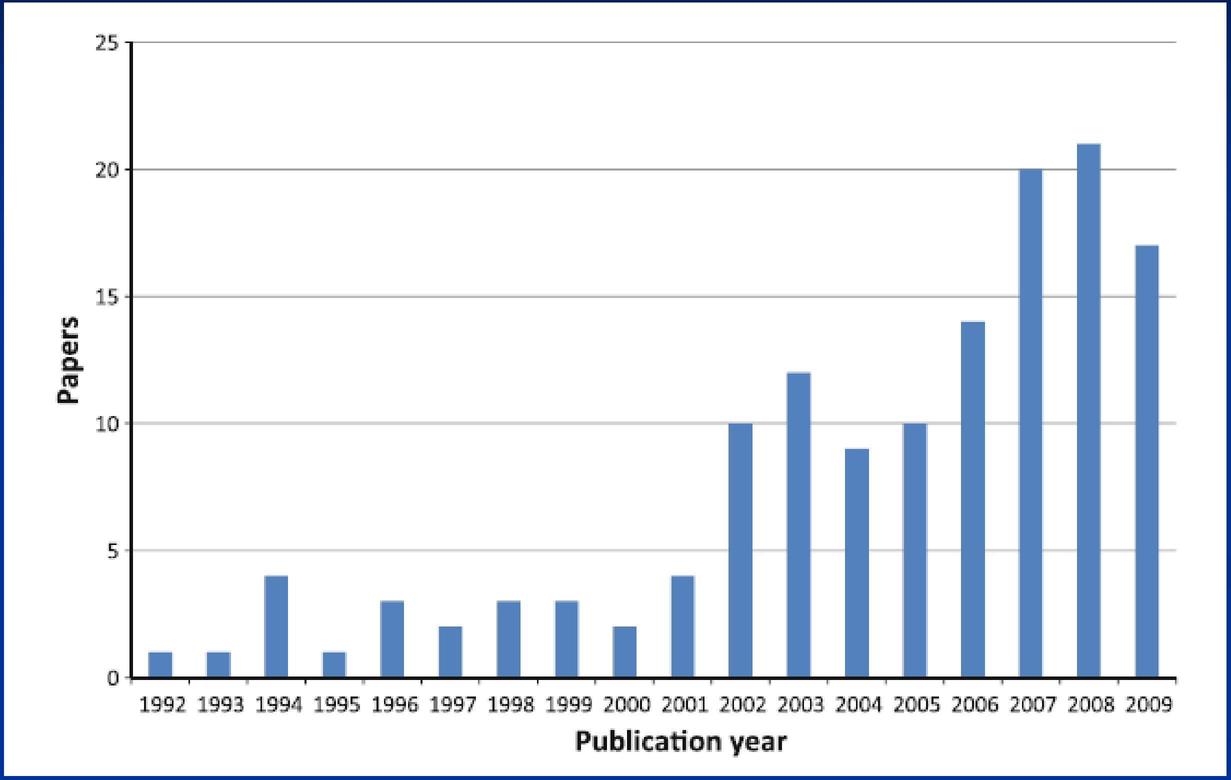
turbines built? 7



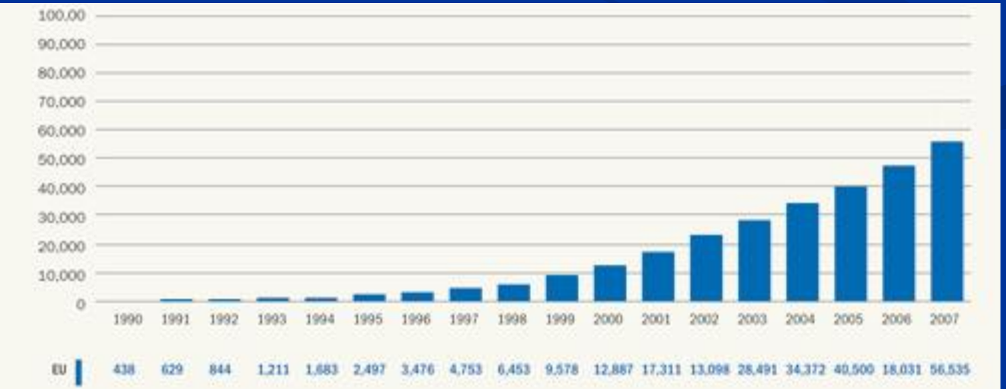


Total capacity of EU wind energy

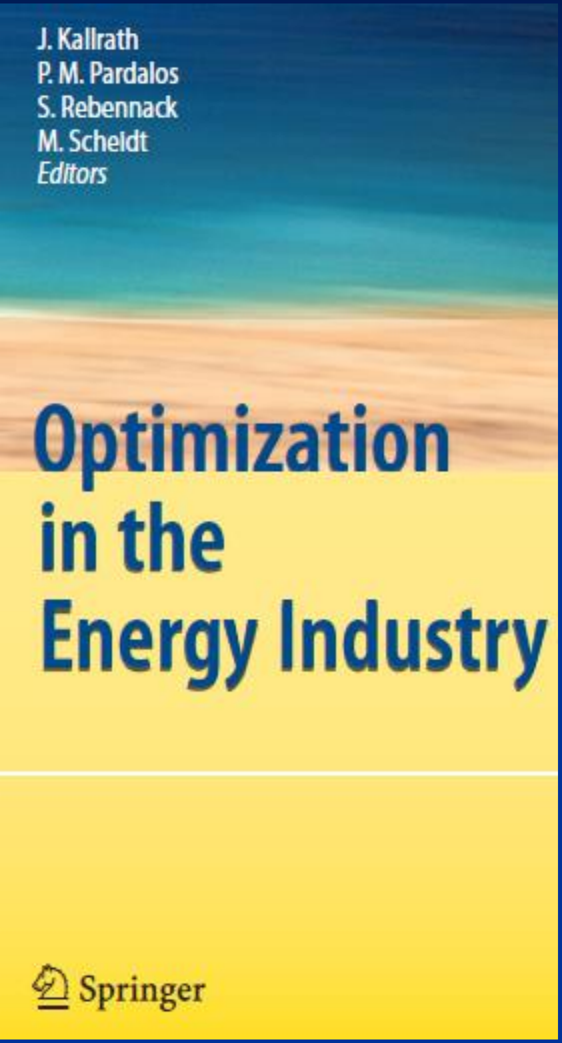
Can OR contribute to the design problem?

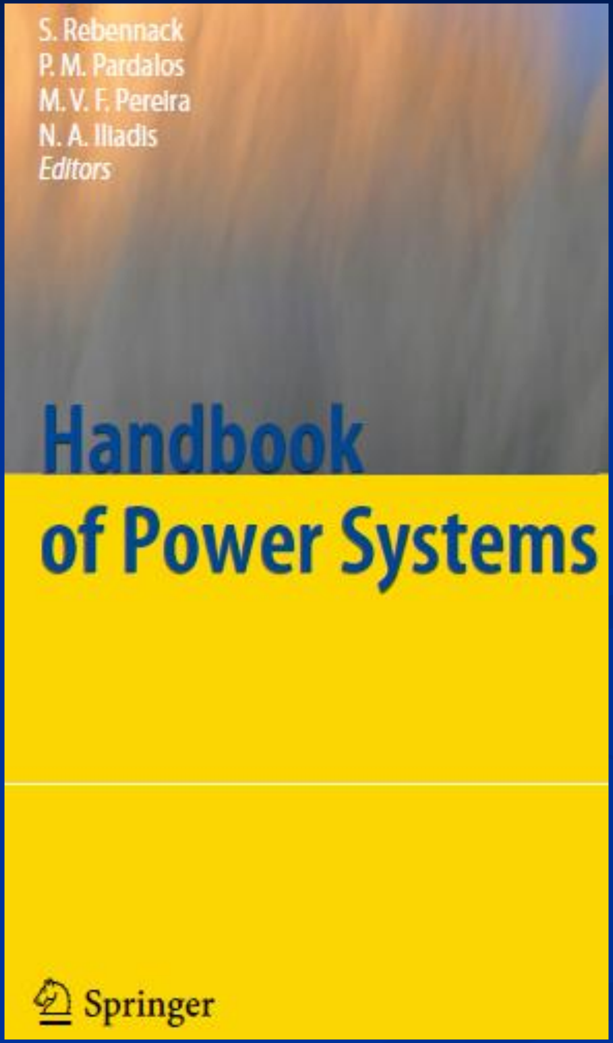


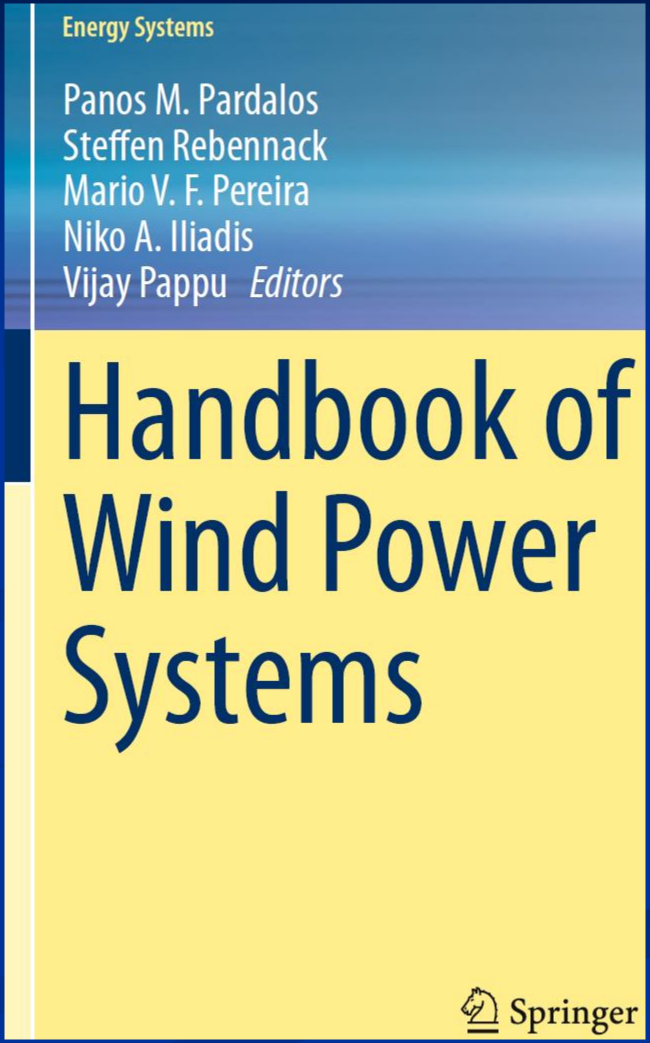
Interest in design
Versus global
installed power



Can OR contribute to the design problem?







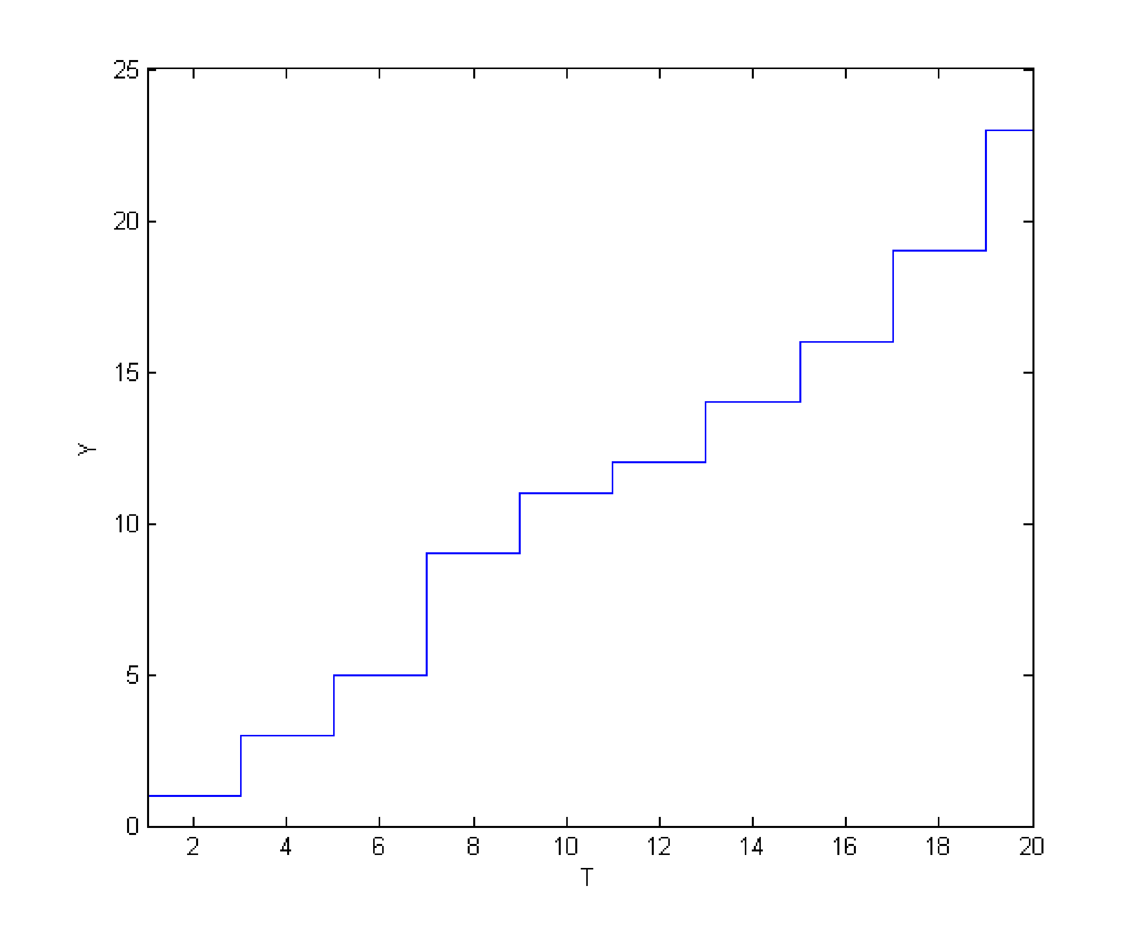
2009 2010 2013

A model for vessel fleet composition for maintenance operations at offshore wind farms

- Decide on bases to use and vessels to buy/rent based on
- Maintenance scheduling of wind farms given the weather and the occurance of breakdowns

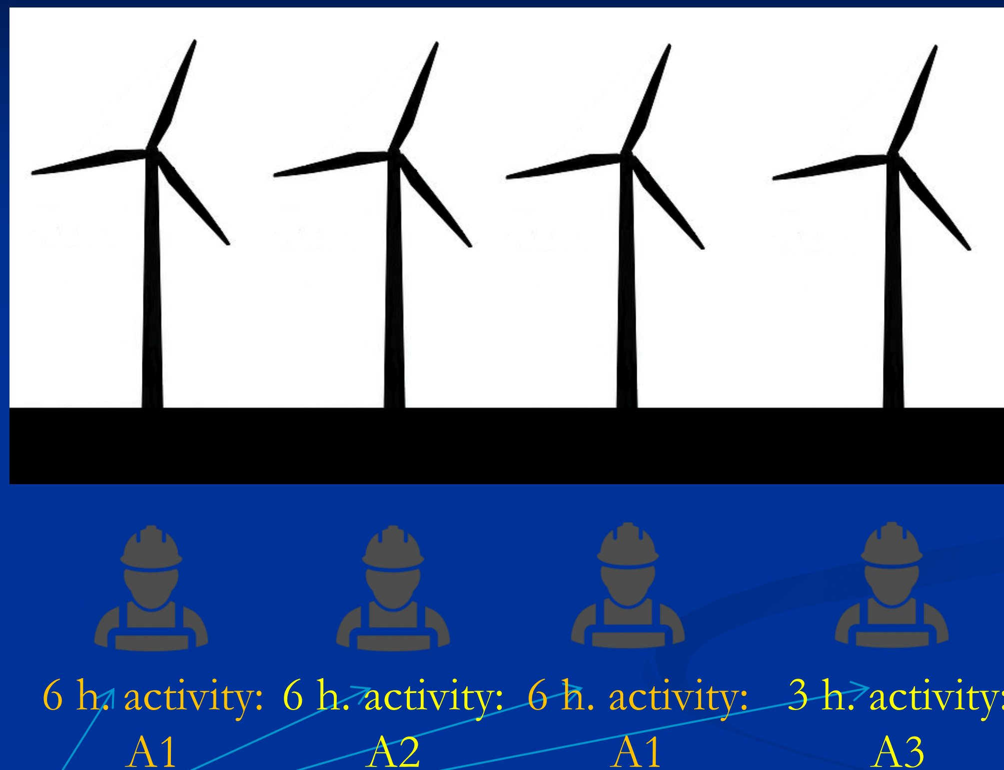
Which bases and vessels to use during a year
level 1

Given: bases and vessels, level 2:



Scenarios:

- number Y_t of turbines requiring repair
- Wind during the year (in each 12 hours shift)
- Preventive Maintenance on other turbines scheduling



Every day (12 hours) which vessel is going to do which “pattern”.
Decisión variable: How many which type of patterns/activities. Not on turbine level.
Level 2 ….. For all year

Scheduling base: enumerating all possible patterns
What can you do in a 12 hour shift
Some operations do not require the vessel to be present

Table: Possible efficient patterns that can be performed from each base-vessel combination

k	v	$\mathcal{P}$
B_1	V_1	$\{(0,0,4,0)\}$
B_1	V_2	$\{(0,0,4,0)\}$
B_1	V_3	$\{(3,0,0,0),(0,2,0,0),(0,0,4,0),(0,0,0,1)\}$
B_1	V_4	$\{(6,0,0,0),(3,3,0,0),(2,2,2,0),(3,0,3,0),$ $(0,3,3,0),(0,0,6,0),(0,0,0,1)\}$
B_2	V_1	$\{(3,0,0,0),(0,2,0,0),(0,0,4,0),(0,0,0,1)\}$
B_2	V_2	$\{(3,0,0,0),(0,2,0,0),(0,0,4,0),(0,0,0,1)\}$
B_2	V_3	$\{(3,0,0,0),(0,2,0,0),(0,0,4,0),(0,0,0,1)\}$
B_2	V_4	$\{(6,0,0,0),(3,3,0,0),(0,6,0,0),(2,2,2,0),$ $(3,0,3,0),(0,3,3,0),(0,0,6,0),(0,0,0,1)\}$
B_3	V_1	$\{(3,0,0,0),(0,0,4,0),(0,0,0,1)\}$
B_3	V_2	$\{(3,0,0,0),(0,0,4,0),(0,0,0,1)\}$
B_3	V_3	$\{(3,0,0,0),(0,2,0,0),(0,0,4,0),(0,0,0,1)\}$
B_3	V_4	$\{(6,0,0,0),(3,3,0,0),(2,2,2,0),(3,0,3,0),$ $(0,3,3,0),(0,0,6,0),(0,0,0,1)\}$

ingredients

Parameters

T	Number of periods (days) in the time horizon
F_k	Fixed cost per year of operating base k
G_v	Charter or depreciation cost for using vessel type v over the complete horizon
D_{st}	Loss due to downtime of performing a maintenance activity in scenario s in period t
C_{kvp}	Cost of executing pattern p
CP_i	Penalty cost for not executing a maintenance activity of type $i \in \gamma$
N_i	Number of hours required by maintenance activity of type $i \in \Gamma$ during the time horizon
PP_i	Number of planned preventive maintenance activities of type $i \in \mathcal{NP}$
H_{it}	Expected hourly downtime cost for a preventive activity of type $i \in \mathcal{NP}$ in period t
M_k	Maintenance technicians available at base $k \in K$ in each shift
MP_p	Required maintenance technician personnel to elaborate pattern p
Q_{kv}	Maximum number of vessels type v that can operate from base k
B_i	Hours spent on an activity of type i in one shift
A_{ip}	Number of activities of type i in pattern p
P_s	Probability of scenario s
Y_{its}	Number of failures of type $i \in \mathcal{NC}$ that are present from period t in scenario s

Sets

$\mathcal{K}$	Set of bases
$\mathcal{V}$	Set of vessel types
$\mathcal{S}$	Set of scenarios
Γ	Set of maintenance activity types
$\mathcal{NP}$	Subset of planned preventive activity types, $\mathcal{NP} \subset \Gamma$
$\mathcal{NC}$	Subset of corrective activity types, $\mathcal{NC} \subset \Gamma$
$\mathcal{N}_v$	Set of activity types that vessel v, is able to perform, $\mathcal{N}_v \subset \Gamma$
$\mathcal{P}$	Set of all possible patterns
$\mathcal{P}_{kv}$	Set possible patterns for a vessel of type v from base k
$\mathcal{PW}_{ts}$	Subset of patterns that can be performed in period t in scenario s when the weather is favourable

Tactical decision variables

$y_k \in \{0, 1\}$	Equal to 1 if base k is used, 0 otherwise
$x_{kv} \in \{0, \ldots, Q_{kv}\}$	Number of vessels type v operated from base k

Operational decision variables

$w_{its} \in \mathbb{Z}^+ \cup \{0\}$	Number of corrective activities of type $i \in \mathcal{NC}$ supported during period t in scenario s
$q_{its} \in \mathbb{Z}^+ \cup \{0\}$	Number of preventive activities of type $i \in \mathcal{NP}$ supported during period t in scenario s
$u_{pts} \in \mathbb{Z}^+ \cup \{0\}$	Number of vessels executing pattern p during period t in scenario s
$r_{ist} \in \mathbb{Z}^+ \cup \{0\}$	Number of corrective activities of type $i \in \mathcal{NC}$ that are not (yet) completed in scenario s in period t
$z_{is} \in \mathbb{Z}^+ \cup \{0\}$	Number of preventive maintenance activities of type $i \in \mathcal{NP}$ not completed in scenario s

Objective

$$\min \sum_{k=1}^{K} F_k y_k + \sum_{k=1}^{K} \sum_{v=1}^{V} G_v x_{kv} + \sum_{s=1}^{S} P_s \left(\sum_{k=1}^{K} \sum_{v=1}^{V} \sum_{p \in \mathcal{P}_{kv}} \sum_{t=1}^{T} C_{kvp} u_{kvpts} \right) + \tag{1}$$

$$\sum_{s=1}^{S} P_s \left(\sum_{i \in \mathcal{NP}} \sum_{t=1}^{T} H_{it} B_i q_{its} + \sum_{i \in \mathcal{NC}} \sum_{t=1}^{T} D_{st} r_{ist} + \sum_{i \in \mathcal{NP}} CP_i z_{is} + \sum_{i \in \mathcal{NC}} CP_i r_{isT} \right)$$

- Fixed costs of operating the bases
- Fixed costs of chartering vessels
- Costs of executed activities throughout the time horizon
- Downtime costs when executing preventive activities
- Downtime costs due to failing turbines
- Penalty costs for not performed preventive activities
- Penalty costs for not performed corrective activities

Types of constraints

$$x_{kv} \leq Q_{kv} y_k \quad \forall k, v \tag{2}$$

$$\sum_{p \in \mathcal{P}_{kv}} u_{pts} \leq x_{kv}, \quad \forall k, v, t, s \tag{3}$$

$$\sum_{v \in V_k} \sum_{p \in \mathcal{P}_{kv}} MP_p u_{pts} \leq M_k, \quad \forall k, s, t \tag{4}$$

$$\sum_{p \in \mathcal{P}} A_{ip} u_{pts} - q_{its} \geq 0, \quad i \in \mathcal{NP}, \forall s, t \tag{5}$$

$$\sum_{p \in \mathcal{P}} A_{ip} u_{pts} - w_{its} \geq 0, \quad i \in \mathcal{NC}, \forall s, t \tag{6}$$

$$\frac{N_i}{B_i}(Y_{its} - r_{ist}) \leq \sum_{\tau=1}^{t} w_{i\tau s} \leq \lceil \frac{N_i}{B_i} \rceil Y_{its}, \quad \forall s, i \in \mathcal{NC}, t = 1, \ldots, T \tag{7}$$

$$N_i z_{is} + \sum_{t=1}^{T} B_i q_{its} \geq N_i PP_i, \quad \forall i \in \mathcal{NP}, s \tag{8}$$

Alcoba, A.G., Ortega, G., Hendrix, E.M.T., Halvorsen-Waere, E.E. and Haugland, D. (2017), A model for optimal fleet composition of vessels for offshore wind farm maintenance, *Procedia Computer Science*, 108, 1512-1521

Computation

Table 3: Number of constraints and variables for different instances of the model varying the number of scenarios ($|\mathcal{S}| = 1, 2, 3$) and the time horizon ($T = 90, 180, 365$)

$\lvert\mathcal{S}\rvert$ \ T	90		180		365	
	N const.	N var.	N const.	N var.	N const.	N var.
1	4,160	10,095	8,294	20,185	16,810	40,905
2	8,304	20,187	16,580	40,347	33,602	81,787
3	12,436	30,269	24,860	60,509	50,392	122,669

Table 4: Execution times, in minutes, for different instances of the model varying the number of scenarios ($|\mathcal{S}| = 1, 2, 3$) and the time horizon ($T = 90, 180, 365$)

$\lvert\mathcal{S}\rvert$ \ T	90	180	365
1	0.25	1.25	62
2	0.6	59	313
3	11.5	196	n/a

Does this model make sense?
Isn't this based on perfect information?

Given a vessel plan, what is the difference between MILP perfect information and realistic (heuristic) scheduling?

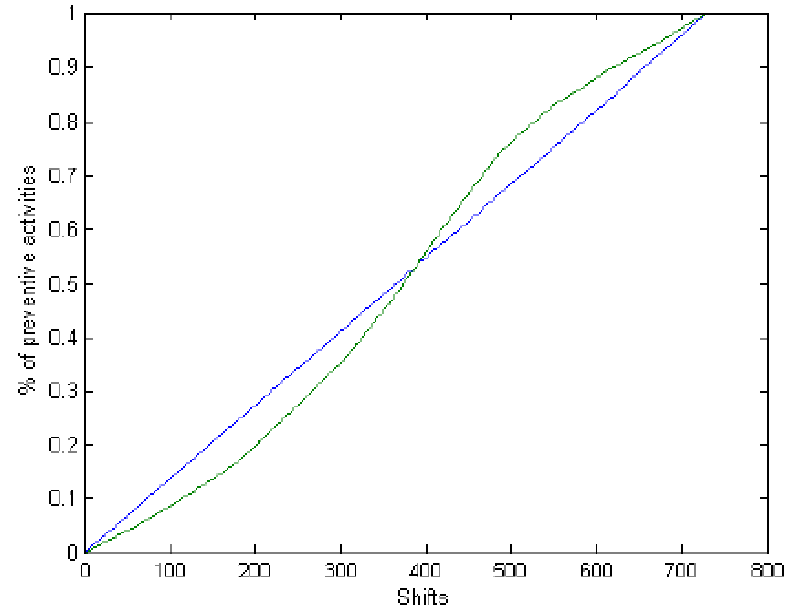


Figure 1: Linear and monthly average approaches to limit preventive activities

Average weather (loss of energy when doing activity), preventive
Current weather
Number of turbines down due to failure

Scheduler based on available information

Algorithm 4 OWFscheduler

```
for i ∈ 𝒩𝒫 do
   RemainHours_i = PP_i × N_i
end for
for t ∈ {1, ..., 2T} do
   Observe realized wind_t and wave_t; 𝒱𝒫_t = ∅
   for v with a k for which x_kv > 0 do
      𝒱𝒫_t = 𝒱𝒫_t ∪ {v} if wind_t <maxWind_v AND wave_t < maxWave_v
      Add observed failure type i to DownAct_i
      Update downtime costs
   end for
   Call Heuristic
end for
Calculate total cost
```

Algorithm 5 Heuristic

```
Set 𝒫_t of possible patterns given (t, 𝒱𝒫_t, DownAct_i,RemainHours_i)
Determine fitness f_p for each pattern p ∈ 𝒫_t
Find r = arg min_{p∈𝒫_t} f_p
Determine IdleCost
while patterns possible and IdleCost< f_r do
   for Choosen pattern r and activities i ∈ List_r do
      Update downtime costs for i ∈ 𝒩𝒫;
      RemainHours_i =RemainHours_i − B_i ∗ A_ir
      Update DownAct_i for i ∈ 𝒩𝒞
      Remove the used vessel and update 𝒫_t correspondingly
      Update f_p, p ∈ 𝒫_t, idleCost and r
   end for
end while
```

Enumerate possible patterns and choose from them

Run 20 scenarios for two vessel plans S1 and S2

Table 1: Associated costs for the MILP optimal solution and the heuristic for tactical decisions S1 and S2

	Total	Pattern	P. D.	C. D.	P. P.	C. P.	Op. S. Cost
MILP S1	10986350	5060220	1117923	558265	0	0	6736408
MILP S2	11472400	5126880	1028245	314890	0	0	6470015
HEUR. S1	13401952	5346330	2296092	1509528	0	0	9151951
HEUR. S2	12958671	5435595	1235124	1287951	0	0	7958671

MILP full enumeration proides a lower bound of the realistic scheduler

For these cases no penalty for non-repair or no preventive maintenance PP CP

Pattern costs

Loss energy due to preventive PD and Corrective (repair) CD

Europt in Almería

Continuing work

Perfect information (anticipation) scheduling provides a lower bound on vessel costs.

We try to get an impression of how much confronting with a realistic scheduler based on available information