

TNO Workshop

Modeling Offshore Wind Logistics: Exploring O&M Accessibility with TNO UWise

WindED Summer School (29 Aug @09:00-10:30)

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Speakers



Louis Huang

Scientist (logistics modeling specialist) at TNO's Wind Energy group, focusing on offshore wind O&M. Works on the UWise simulation tool and R&D projects in data-driven maintenance, robotics, and floating wind/solar.

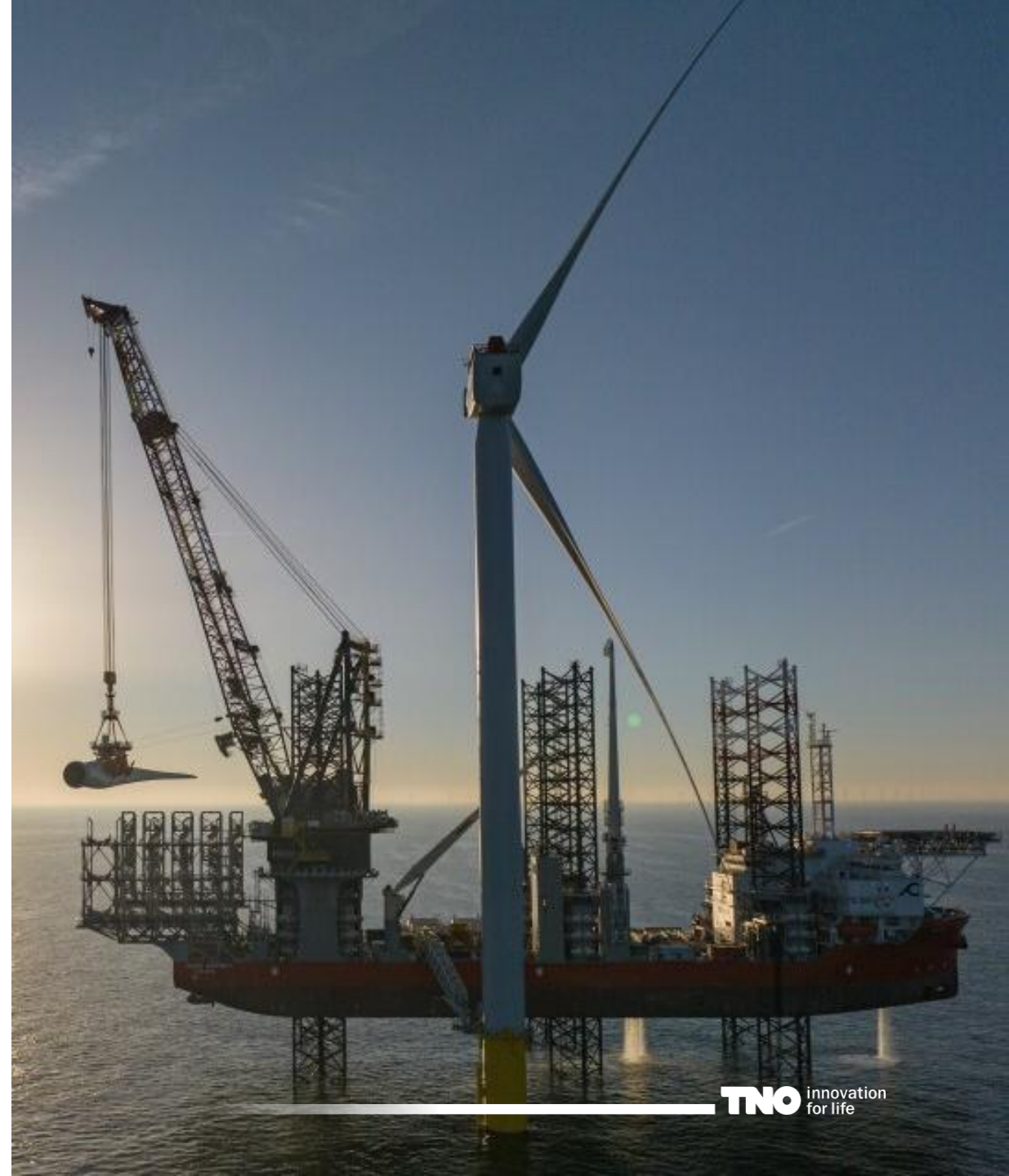


Janaki Mohanan Nair

Project Manager at TNO's Wind Energy group with 13+ years in the energy sector. Leads projects on wind energy and robotic applications for smart operations.

Goal of Workshop

- ❑ Explore offshore wind logistics with TNO's UWise tool
- ❑ Understand site accessibility, downtime, and costs
- ❑ Compare vessel strategies (CTV vs. SOV)
- ❑ Hands-on case study discussion



Agenda

09:00 – 09:05	Introduction
09:05 – 09:15	Warm-Up
09:15 – 09:45	Logistics Modelling Fundamentals
09:45 – 09:55	Coffee Break
09:55 – 10:25	Case Study
10:25 – 10:30	Closing



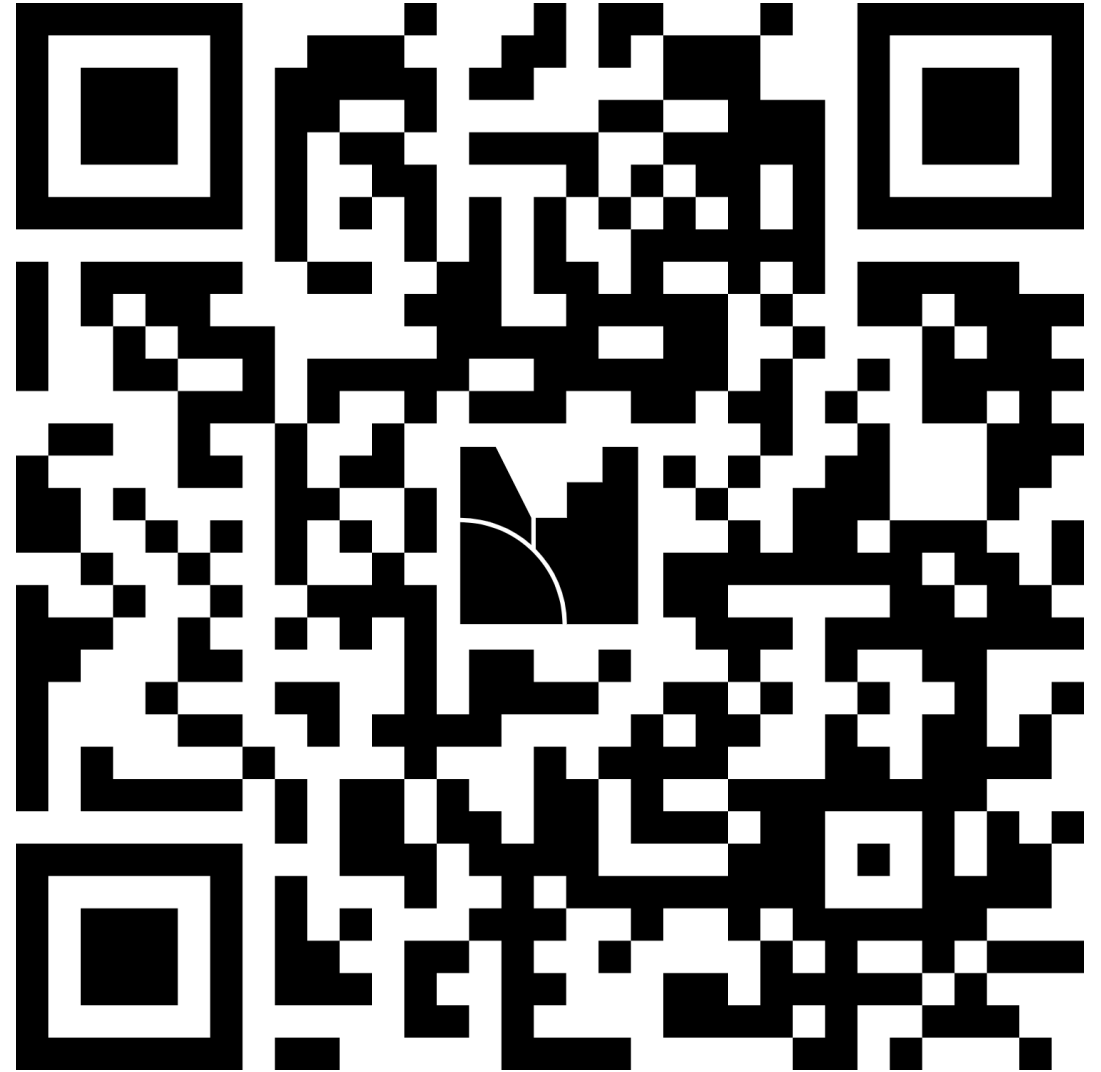
How much do you know about offshore wind O&M?

Quiz time!

- Go to www.menti.com and use the code:

4606 6884

- Or scan the QR code:



Why is offshore O&M research relevant?

For modern offshore wind farms:

O&M → **25-35%** of Levelized Cost Of Electricity (LCOE)

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}}$$

Example:

- 700 MW offshore wind farm, LCOE 50 €/MWh
- O&M share 30% → 15 €/MWh
- 10% O&M reduction via **innovations** → 1.5 €/MWh savings
- Annual savings: 700MW x 8760h/y x 40% (capacity factor) x 1.5 €/MWh ~4 M€/y

**LARGE COST-SAVING
POTENTIAL!**

The exact values are site-specific!

- **O&M cost drivers**: wind/wave conditions, O&M strategy, technologies, distance to ports, etc.

Challenges in O&M Cost Estimation

Challenge 1 – Failure occurrence uncertainty

- ❑ Turbine components (blades, gearboxes, converters) can fail unpredictably.

Challenge 2 – Marine weather dependency

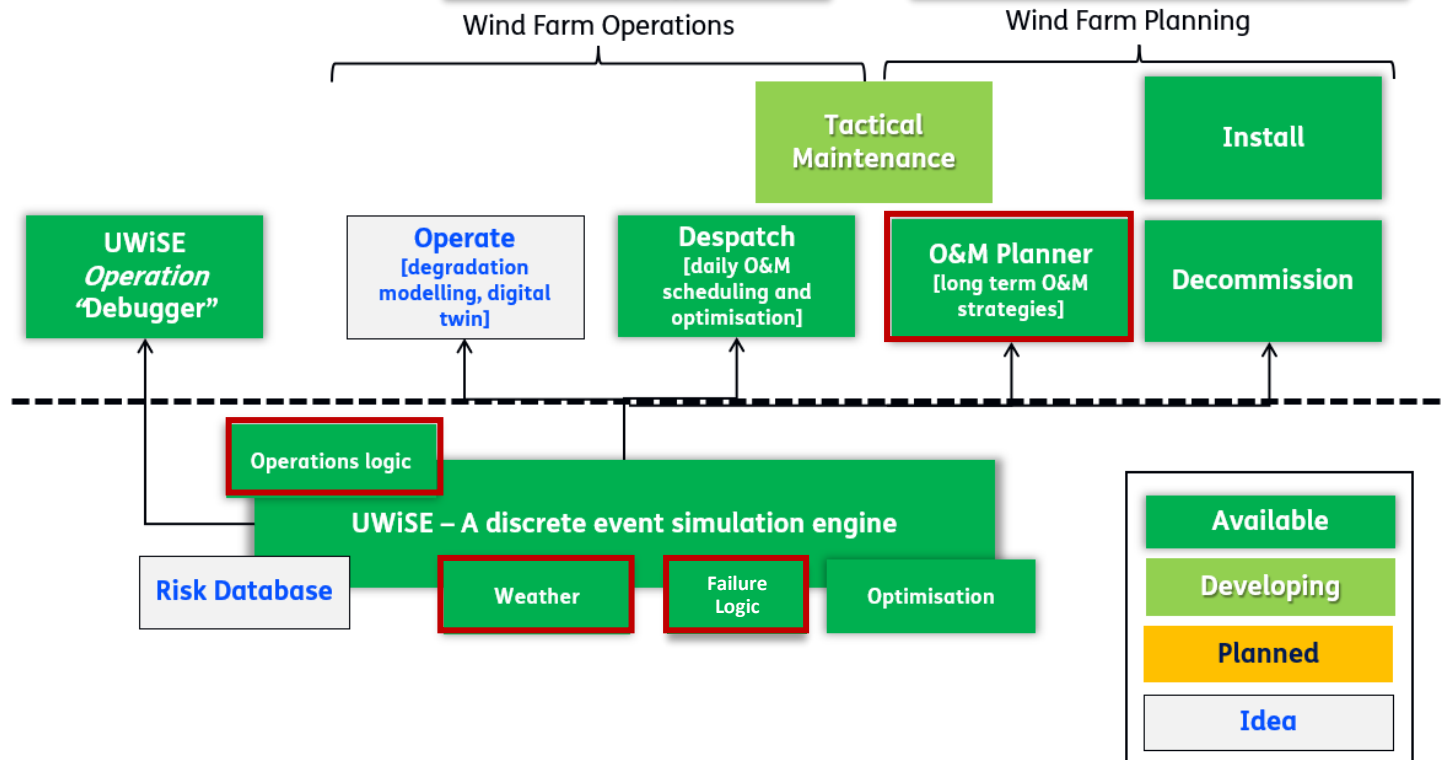
- ❑ Access to turbines depends heavily on weather (e.g. wind, wave height),
- ❑ Lack of “weather windows” can delay repairs for days or even weeks, causing significant downtime losses, which is difficult to be estimated.

Challenge 3 – Dispatching & resource constraints

- ❑ Limited vessels and technicians must be allocated efficiently across many turbines.
- ❑ Poor dispatching can lead to long waiting times and reduced energy production.

Solution – Logistics Modelling (UWISE)

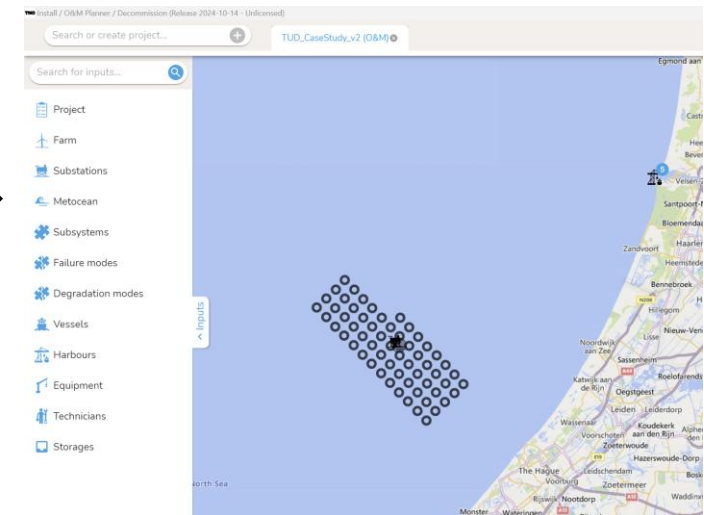
The software landscape: **Short-term (days-weeks)** **Mid/Long-term (months-years)**



Front-end
Simple, easy to use,
professionally
programmed

Back-end
One standard simulation
engine.
Additional parts needed
for managing multiple
simulations and
optimisation.

Map-based User Interface



A bit of UWise history

The WE Group of TNO (previously ECN) has 20+ years of experience in decision-support logistics models for offshore wind



Between ~2000-2015 ECN developed industry standard tools:

- ECN O&M Tool (Excel-based)
- ECN O&M Calculator (OMCE, Matlab-based)
- Plus many other tools (ECN Access, ECN Fleet Leader, etc.)

With growing industry maturity, TNO continued development and brought the different tools under a single R&D-focused software platform → **UWise**

Some clients / R&D partners:



1. Failure Uncertainty – Weibull Distribution

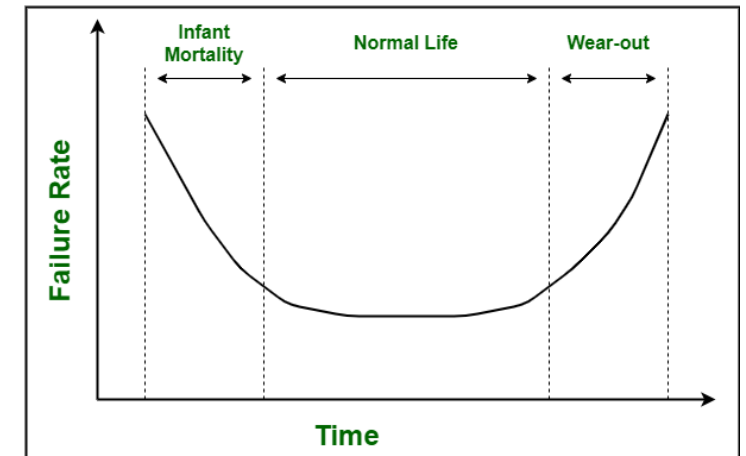
$$\text{Probability Density Function (PDF): } f(t) = \left(\frac{\beta}{\eta^\beta}\right) (t^{\beta-1}) \left(e^{-\left(\frac{t}{\eta}\right)^\beta}\right)$$

β (shape factor): Determines failure behavior over lifetime

- $\beta < 1 \rightarrow$ “Infant mortality” (failures decrease with age, e.g. early defects).
- $\beta = 1 \rightarrow$ Constant failure rate (like random failures, exponential case).
- $\beta > 1 \rightarrow$ “Wear-out” (failures increase with age, e.g. fatigue, aging).

η (scale factor): Sets the characteristic lifetime of a component

\rightarrow Mean Time Before Failure (MTBF), e.g. 5 years, 10 years...

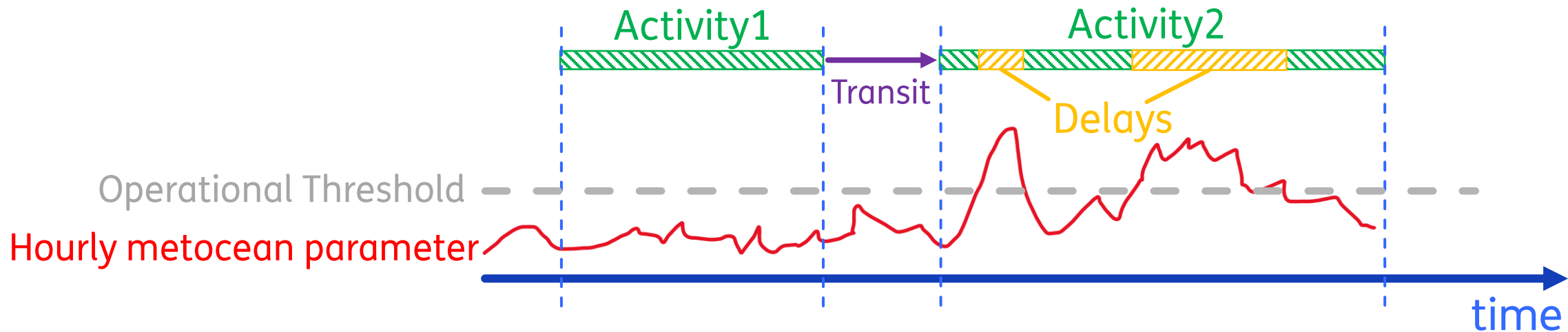


Bathtub Curve

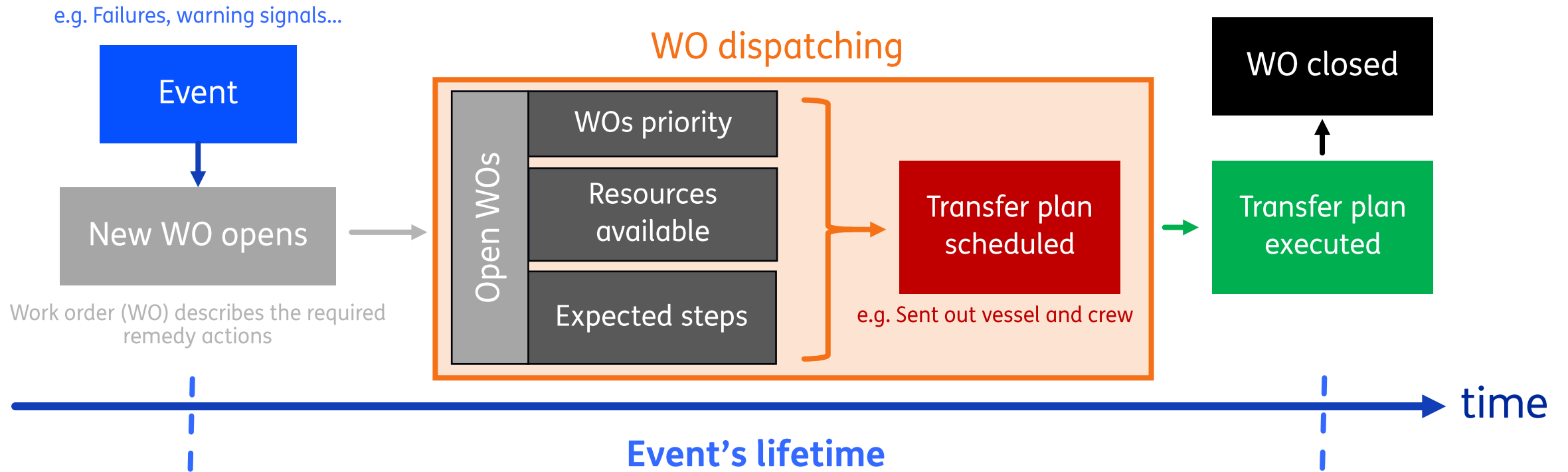
2. Marine Weather Dependency

Simple operation for example:

Activity 1 → Vessel Sailing (Transit) → Activity 2



3. Dispatch/ Planning Logic



Impacts of an event:

- **Direct cost:** Vessel chartering, technician hiring, spare part purchase...etc
- **Downtime cost:** Turbine malfunction due to failure, shutdown during maintenance...etc

Assuming there is an offshore wind farm....

What information do you need to estimate the O&M cost?

- Go to www.menti.com and use the code: 8815 0490
- Or scan the QR code:

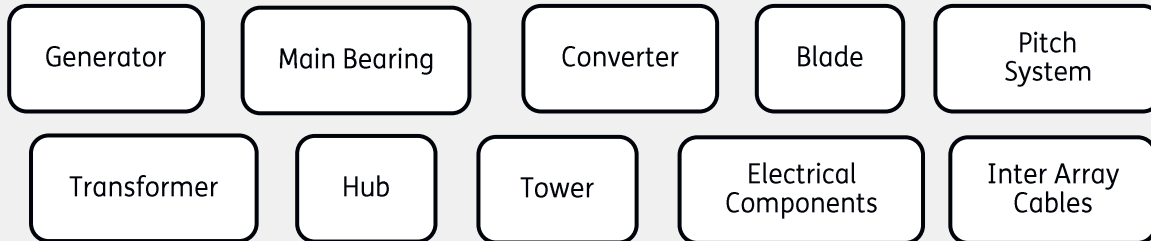


Key Elements in Logistics Modelling

1. General

Wind farm layout, port location, cabling route

2. Wind Turbine Component Breakdown (example)



3. Failure modes & failure rates per component:

- Blade leading-edge erosion, structural cracks...
- Generator overheating, electrical faults
- Bearing damage from high loads and vibration
- Subsea cable damage
-

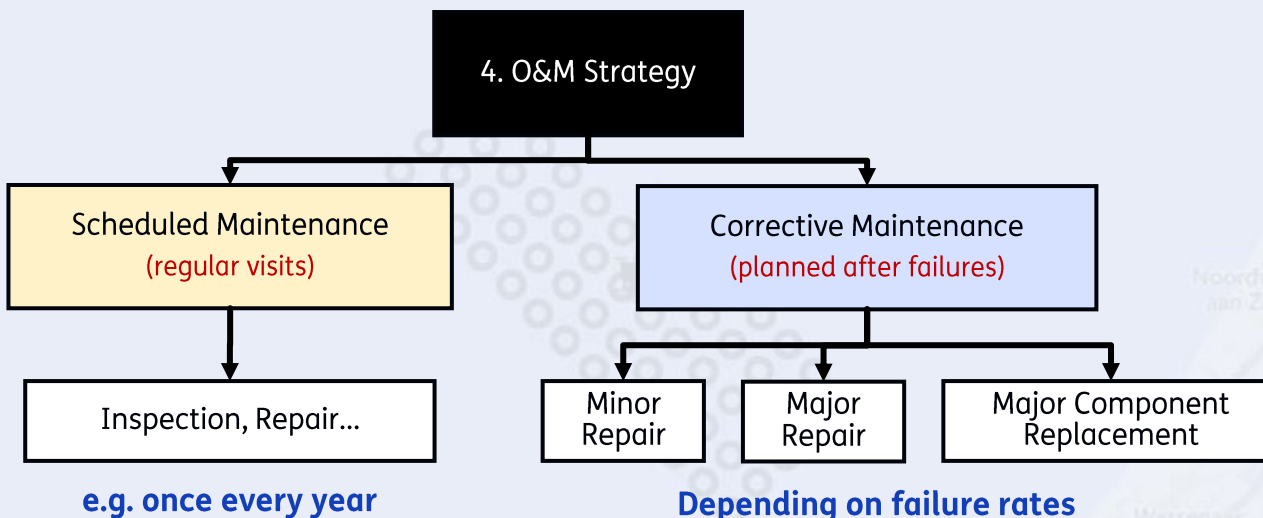
5. Method Statements

Operational steps, weather limits of each step...etc

6. Technician Characteristics

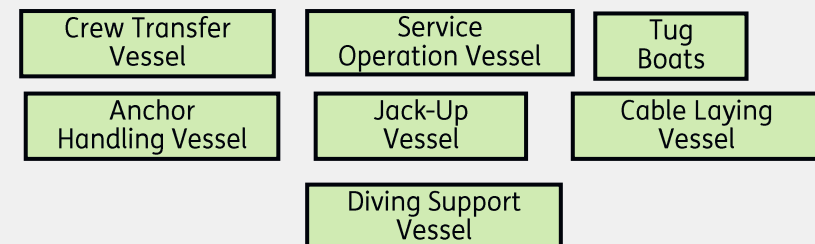
Day Rate, 12h shift, 24h shift...etc

4. O&M Strategy



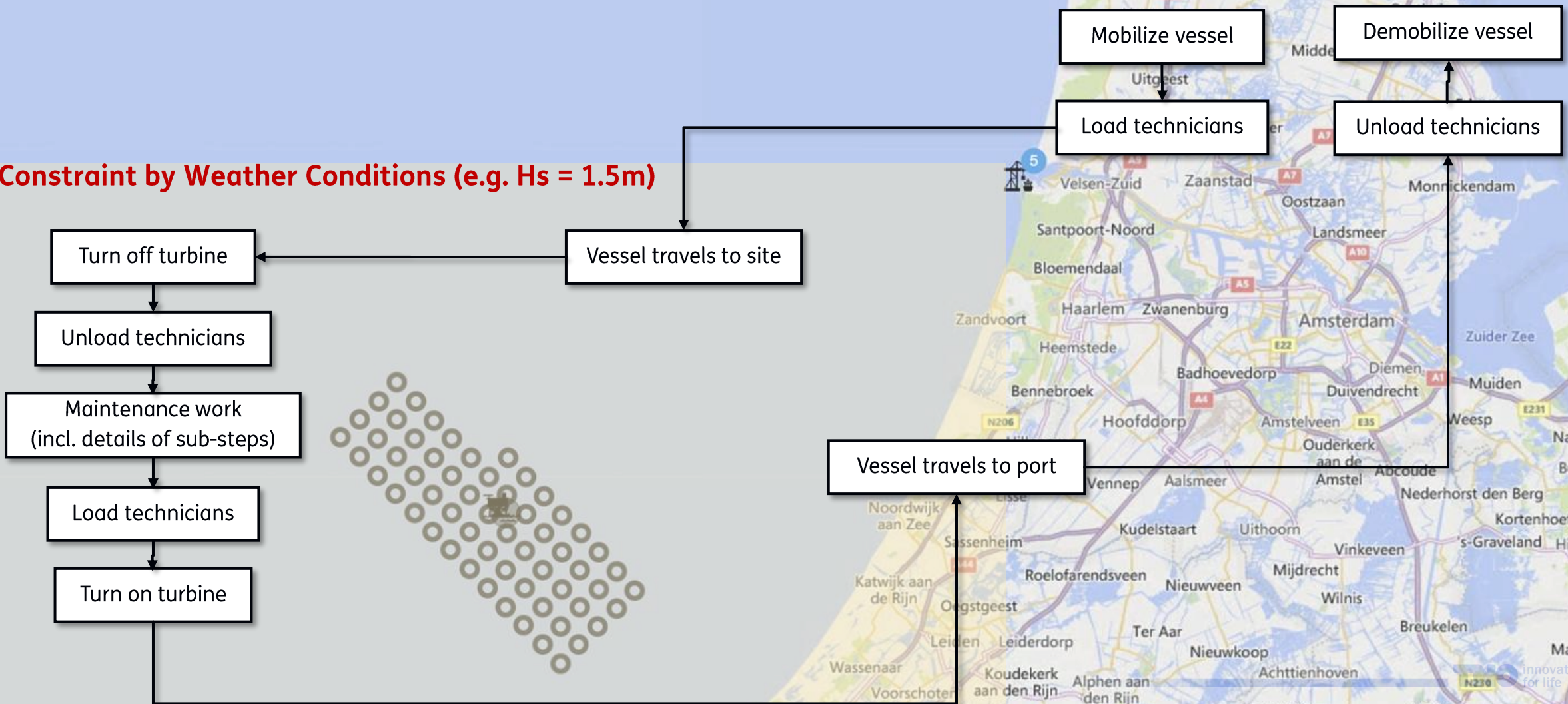
7. Vessel Characteristics:

Weather Limits, Day Rate, Mobilization Rate...etc



Typical Maintenance Process

Constraint by Weather Conditions (e.g. $H_s = 1.5\text{m}$)

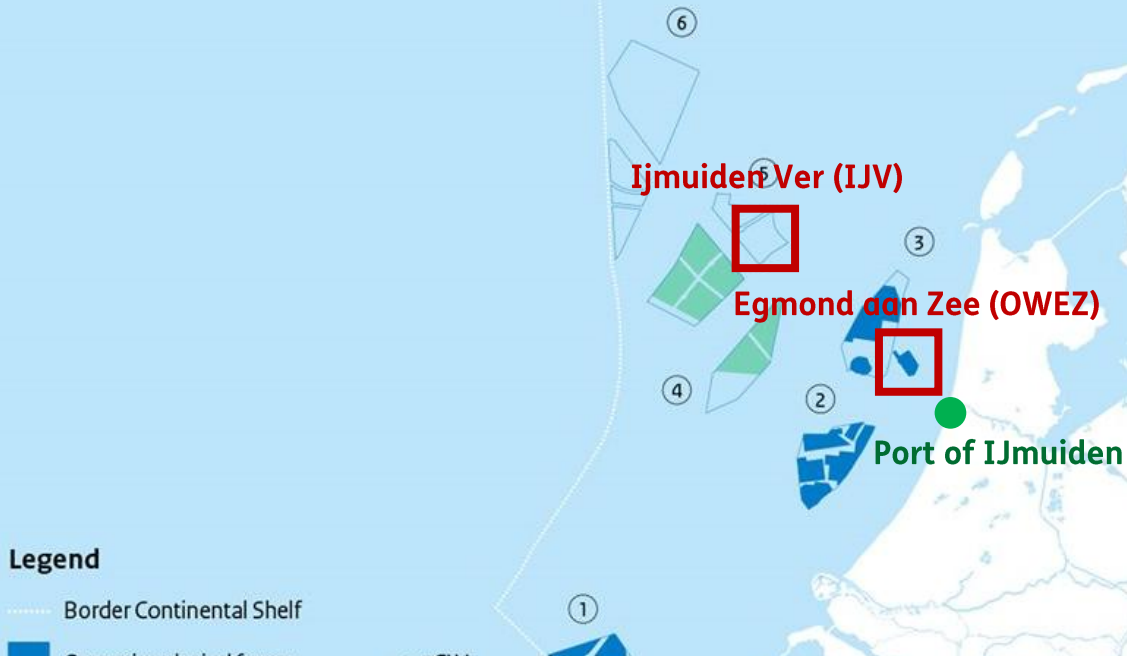


Coffee Break (10 min)

Next: Case Study (CTV v.s. SOV)

Which vessel strategy is more ideal for which site?

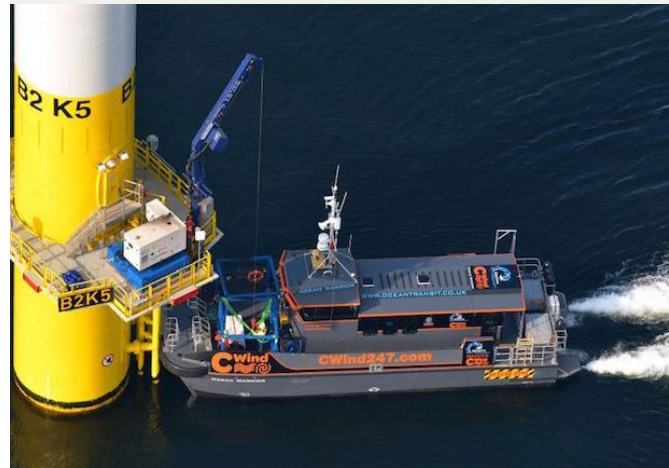
Roadmap Offshore Wind Energy 21 GW



Comparing with two major KPIs:

- Vessel Cost (m€/y)
- Downtime Loss (m€/y)

Crew Transfer Vessel (CTV)



- Sailing back and forth daily
- Daylight work only (06:00-18:00)
- Max. Significant wave height (Hs) ~1.5 m

Service Operation Vessel (SOV)



- Parked at site with accommodation
- 24h operation
- Max. Significant wave height (Hs) ~3.0 m

A Bit More Information....

Wind Farm Size	1GW (10 MW x 100 turbines)
Capacity Factor	~40%
Electricity Price	80 €/MWh
CTV Day Rate	4 k€/day
SOV Day Rate	35 k€/day
CTV Strategy	3 CTVs are chartered at port all year round
SOV Strategy	1 SOV is chartered at site all year round

Maintenance event table

Maintenance Type	Est. Frequency (1/turbine/y)	On-Turbine Work Duration (h/event)
Minor Repair	3	15
Major Repair	1	30
Scheduled Inspection	1	24
* Major Replacement (required JUV) is excluded from this exercise.		

Back-Of-The-Envelope Calculation

1. What is the est. annual vessel cost for:

CTV strategy (m€/y)

SOV strategy (m€/y)

2. What is the est. downtime cost (m€/y), based on the maintenance event table?

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Back-Of-The-Envelope Calculation

1. What is the est. annual vessel cost for:

CTV strategy (m€/y)

$4 \text{ k€/d} \times 365 \text{ d} \times 3 \text{ CTVs} \sim 4.4 \text{ m€/y}$

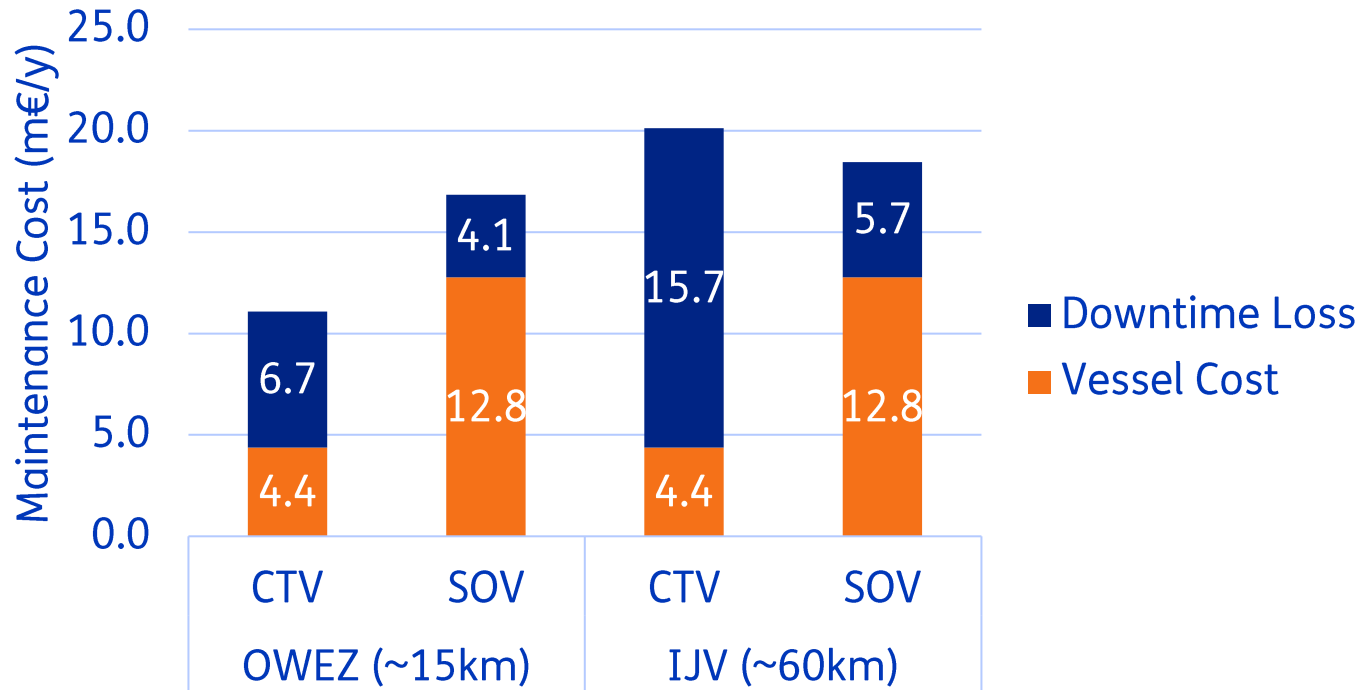
SOV strategy (m€/y)

$35 \text{ k€/d} \times 365 \text{ d} \times 1 \text{ SOV} \sim 12.8 \text{ m€/y}$

2. What is the est. downtime cost (m€/y), based on the maintenance event table?

- Downtime per turbine per year
 $= 3 \times 15 + 1 \times 30 + 1 \times 24 \sim 100\text{h}$
- Annual energy loss per farm
 $= 100\text{h} \times 1000 \text{ MW} \times 40\% = 40,000 \text{ MWh}$
- Annual revenue Loss per farm
 $= 40,000 \text{ MWh} \times 80 \text{ €/MWh} \sim 3.2 \text{ €/y}$

UWiSE results



What is missing in back-of-envelope calculation?

- For all the scenarios, downtime loss are all underestimated
 - CTV strategy in IJV (far-shore) has significant increase in downtime
- exceed the cost benefits of CTV

Site	Vessel Strategy	Vessel Cost		Downtime Loss	
		Est.	UWiSE	Est.	UWiSE
-	-				
OWEZ (near-shore ~15km)	CTV	4.4	✓	3.2	6.7
	SOV	12.8	✓		4.1
IJV (far-shore ~60km)	CTV	4.4	✓		15.7
	SOV	12.8	✓		5.7

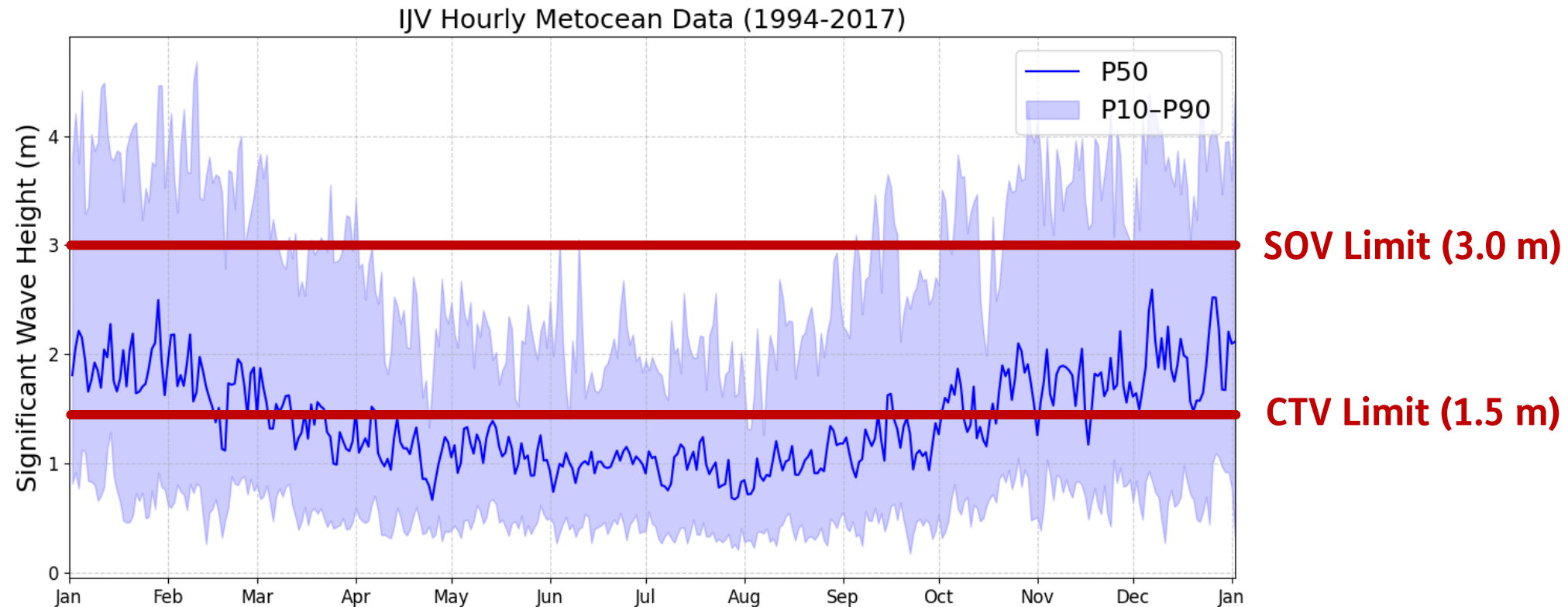
1. Weather dependency was ignored

We assume vessels can work every day!

In reality, CTVs are often blocked in winter ($H_s > 1.5$ m).

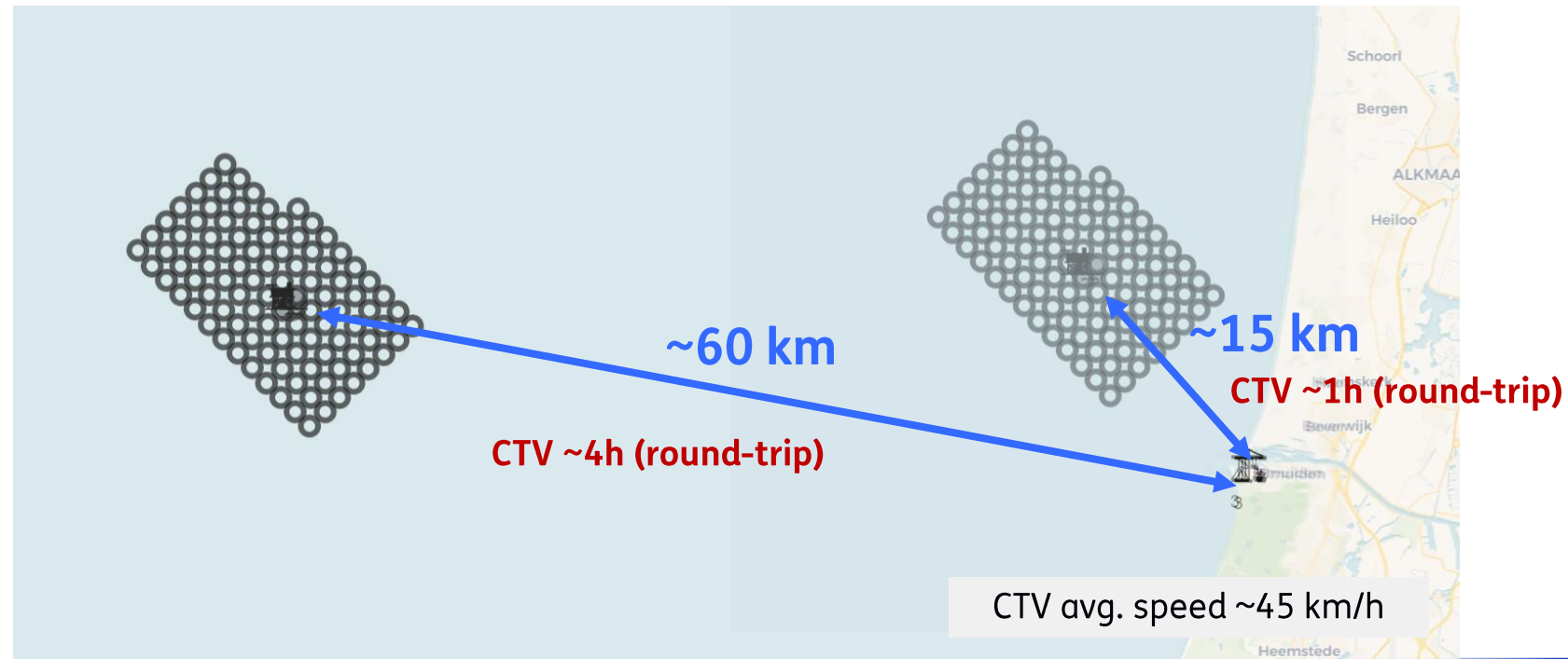
SOVs have higher accessibility (H_s limit 3.0 m).

→ The days when vessel cannot sail out, some (major) failures may already stop the production of turbines, causing extra downtime



2. Vessel Travel & technician transfer time were ignored

- ❑ We assume maintenance starts immediately, without considering transport time!
→ In far-shore site, there is much more time spend on traveling, delaying the repair of major failure (more downtime)
- ❑ If SOV is chartered at site, it saves a lot of vessel traveling time



3. Resource availability was ignored

- ❑ Multiple turbines may be waiting → downtime accumulates more than linearly.

4. SOV is normally applied with 24h operation

- ❑ Once SOV is chartered at site, multiple shifts of technicians would enable 24h operation, making the maintenance more efficient!

5. Capacity factor assumed fixed

- ❑ In reality, production is wind-dependent → losing hours in winter (high winds) costs more.

Closing Remarks

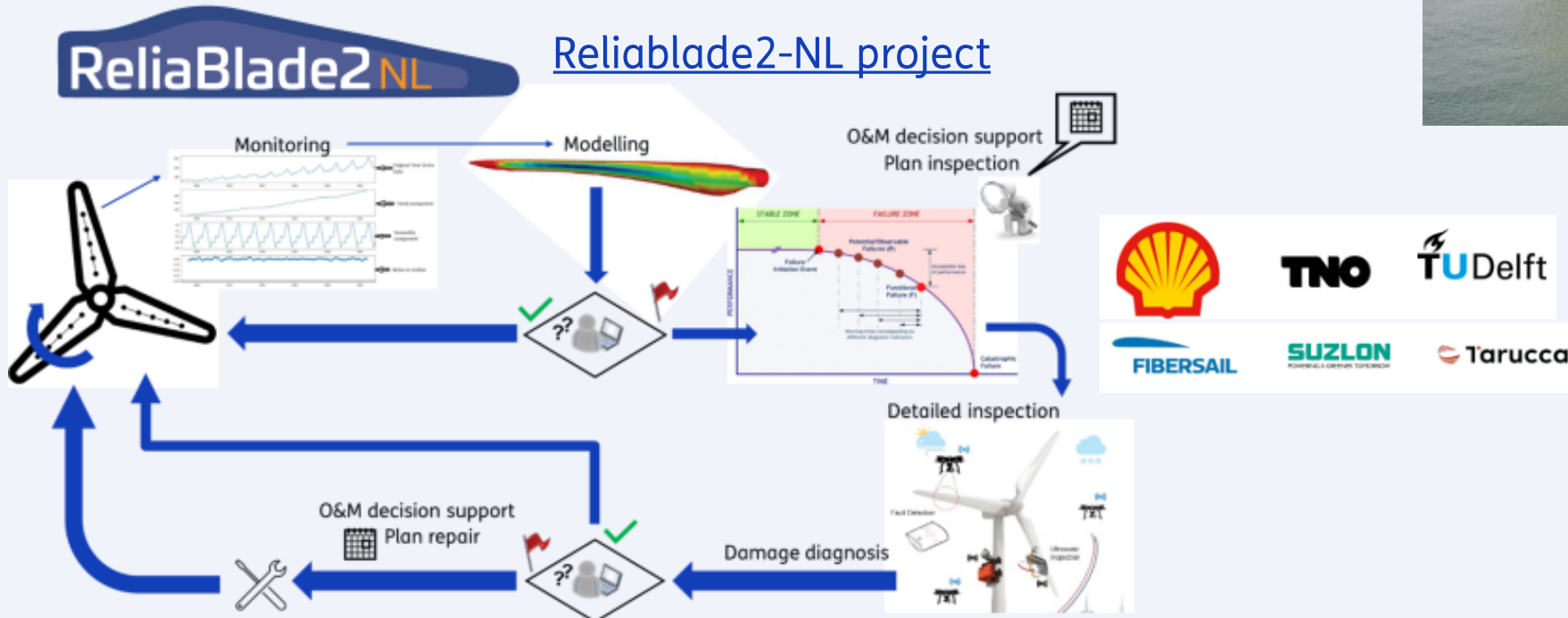
- ❑ Vessel type & distance strongly impact O&M downtime and costs.
- ❑ CTV: cheaper, near-shore, strict with wave height
SOV: expensive, far-shore, reduces weather delays.
- ❑ Back-of-envelope calculations are useful, but real simulations capture weather, travel, and scheduling complexities.
- ❑ Variability in waves, failures, and accessibility impacts planning and risk management.



TNO Wind IOMD research priorities

- Smart, predictive & opportunistic O&M
 - Digital twin algorithms and tools for RUL prognosis
 - O&M decision support
 - Alternative methods for MCR

Floating Wind (FOWTIOM) project



TNO Wind IOMD research priorities



- **IOMD Robotization & automation**
 - Identification of opportunities & cost-benefit analysis
 - Planning & dispatching support tools

[PRIMA USV project](#)



AIRTuB ROMI



<https://youtu.be/lQNJAuMv7AM>
https://youtu.be/mXQWhop_G1k



TNO Wind IOMD research priorities

- **Cluster-level O&M optimization**
 - Multi-farm policies
- **Integrated systems offshore**
 - IOMD of offshore electrolysis plants, OFPV plants, storage systems
- **Offshore wind sustainability**
 - IOMD Emission footprint quantification & reduction strategies
 - End of life modelling

[EoLO-HUBs project](#)

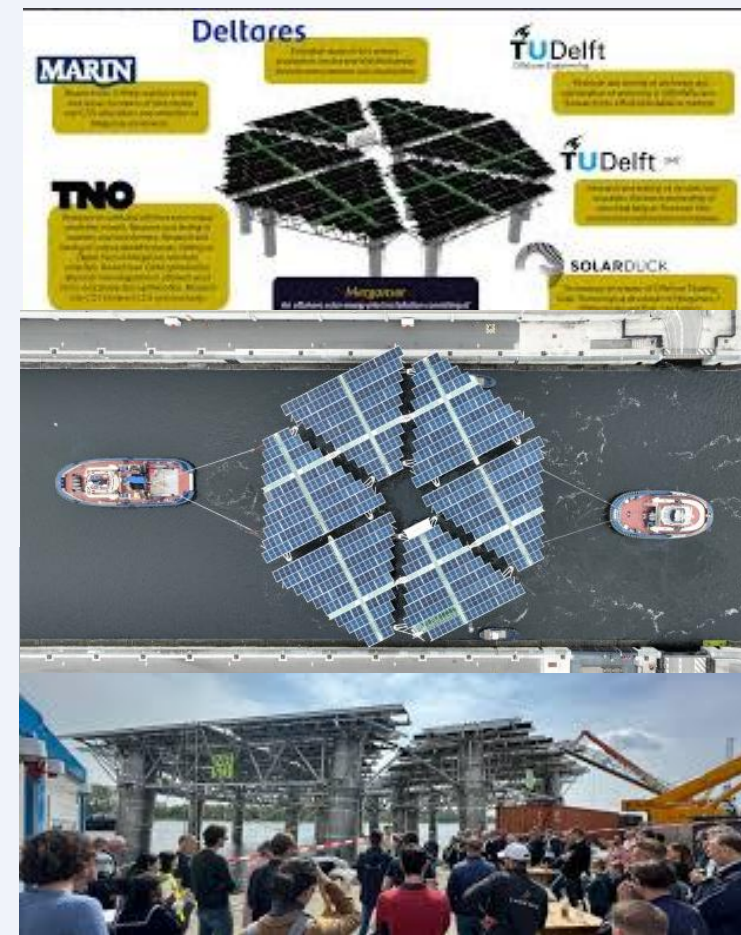


Co-funded by the
European Union

[North Sea Energy Programme](#)

North
Sea
Energy

[DEI+ Pilot Merganser project](#)



Recent Publications on UWise Logistics Modelling

[1] Huang, L. J., Mancini, S., & de Jong, M. (2025). Modeling marine assembly logistics for an offshore floating PV plant under weather constraints. *J. Mar. Sci. Eng.*, 13(8), 1493.

[2] Mancini, S., Bloothoofd, J., Dighe, V., & van der Mijle Meijer, H. (2024). Development and verification of a discrete event simulation tool for offshore wind and solar decommissioning. *J. Phys.: Conf. Ser.*, 2745(1), 012010.

[3] Dighe, V. V., Huang, L. J., Montfort, J. H., & Serraris, J. J. (2024). Improving O&M simulations by integrating vessel motions for floating wind farms. *J. Mar. Sci. Eng.*, 12(11), 1948.

A woman with long blonde hair, wearing a purple knit sweater, stands in a field of tall grass. She is holding a small white model of a wind turbine in her right hand, extending it towards the left. The background shows a coastline with waves and a cloudy sky. A large blue circular graphic is overlaid on the left side of the image, containing the text.

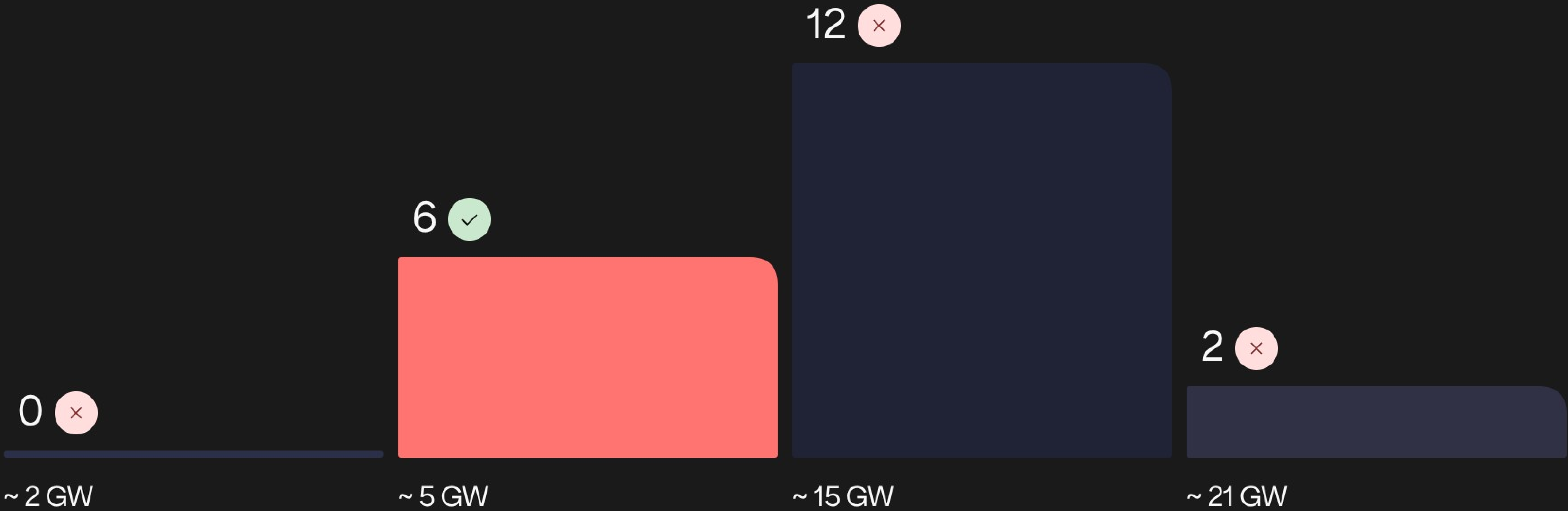
Thanks for the attention
Website - UWiSE by TNO

How much do you know about offshore wind O&M?

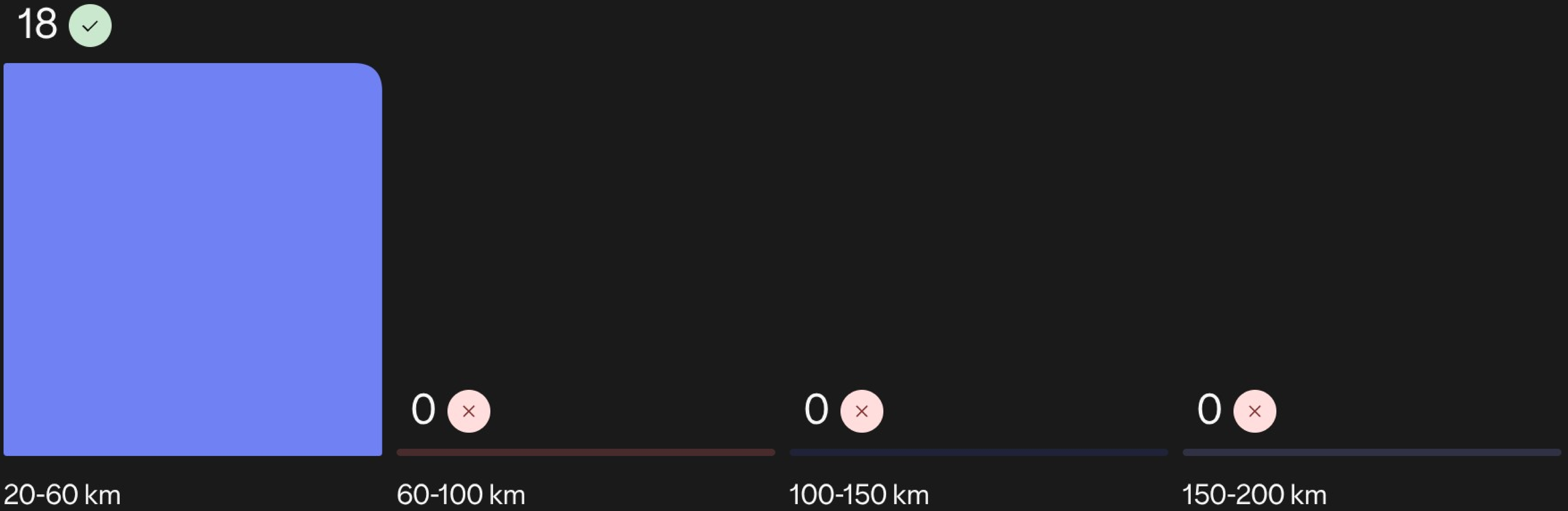
10 Questions



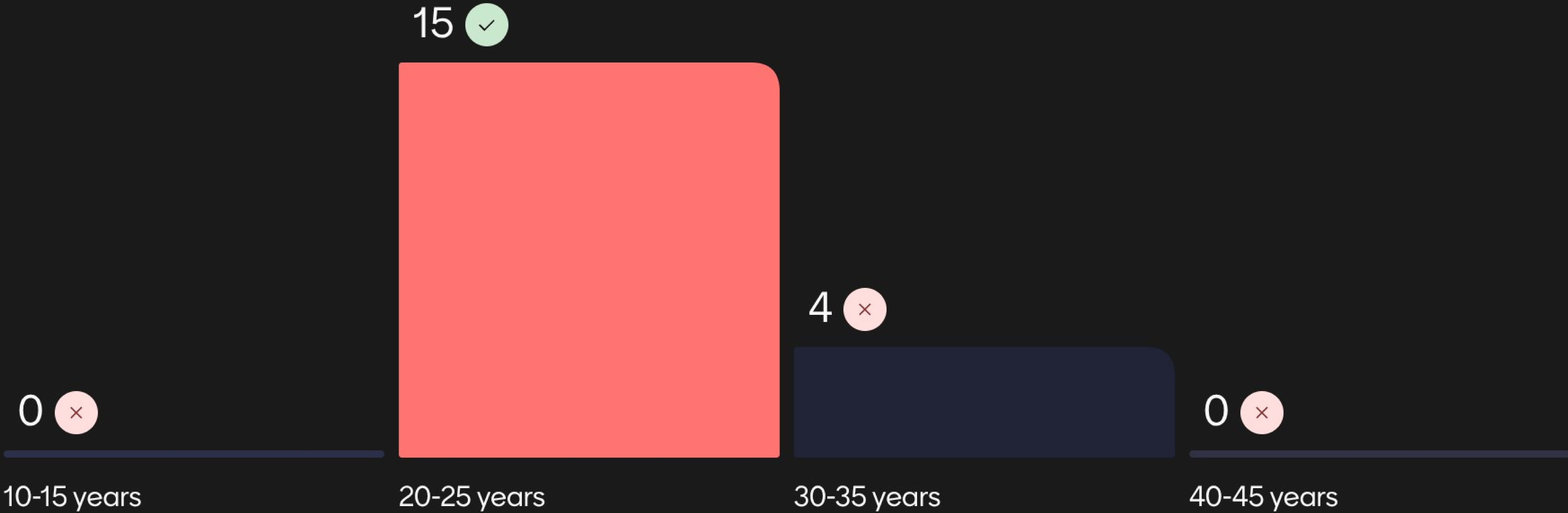
1. What is the current Dutch offshore wind capacity?



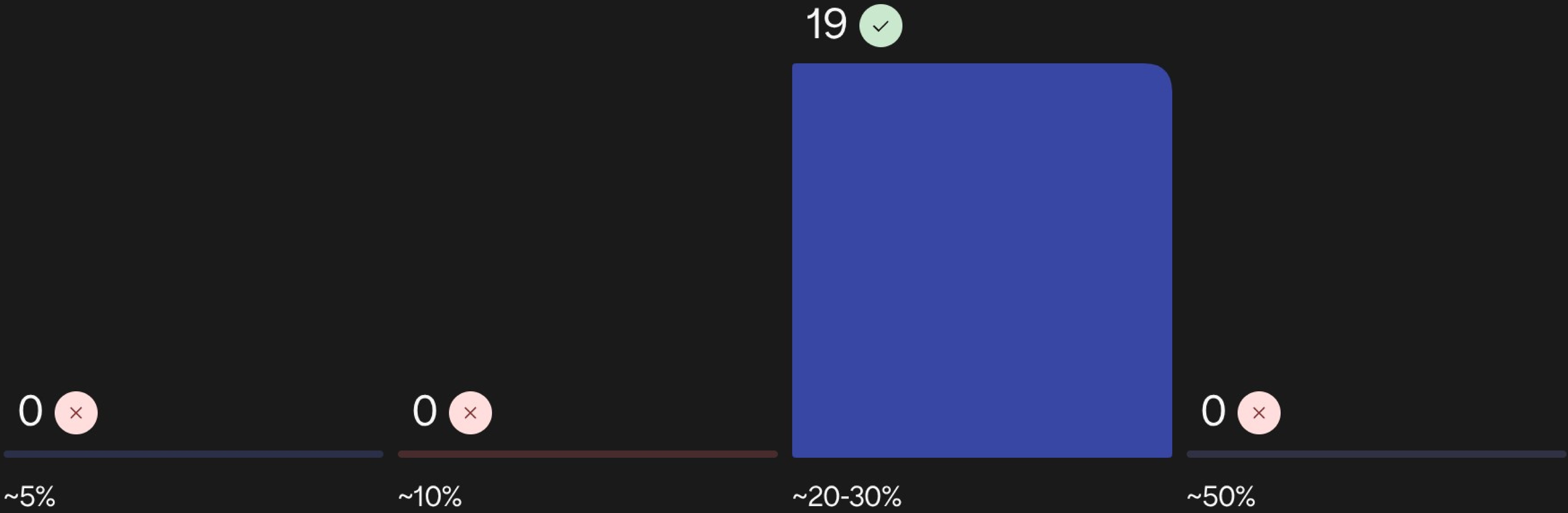
2. What is the average distance of Dutch OWFs from the shore?



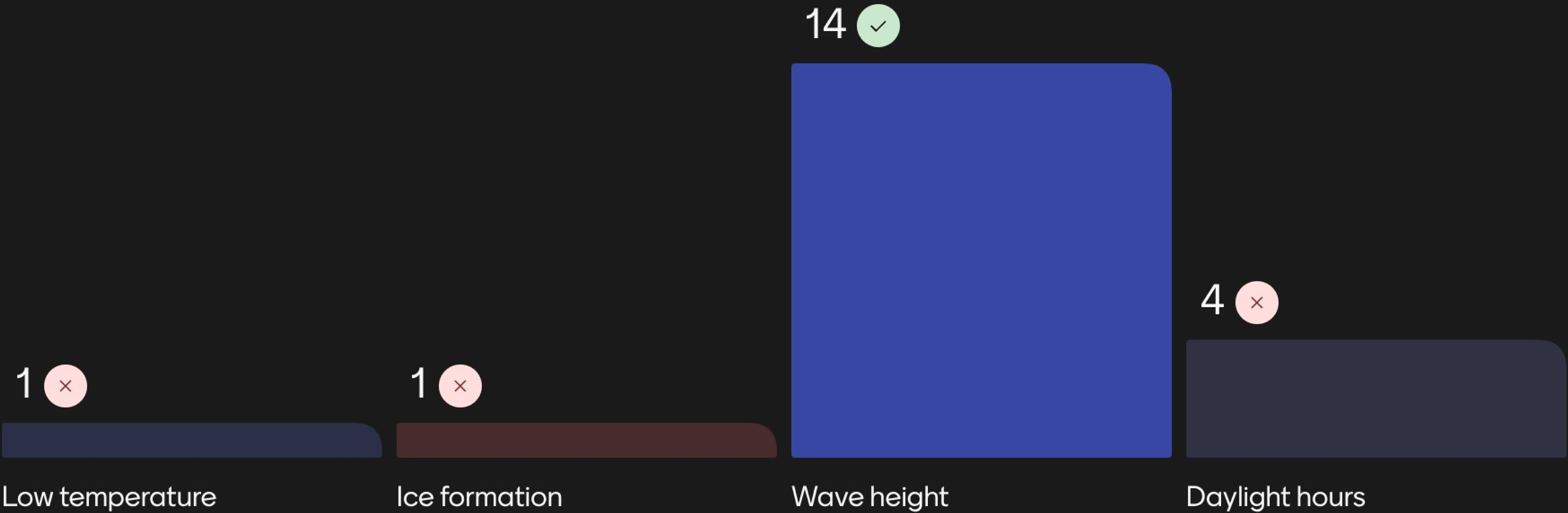
3. What is the typical operational lifetime of an OWF?



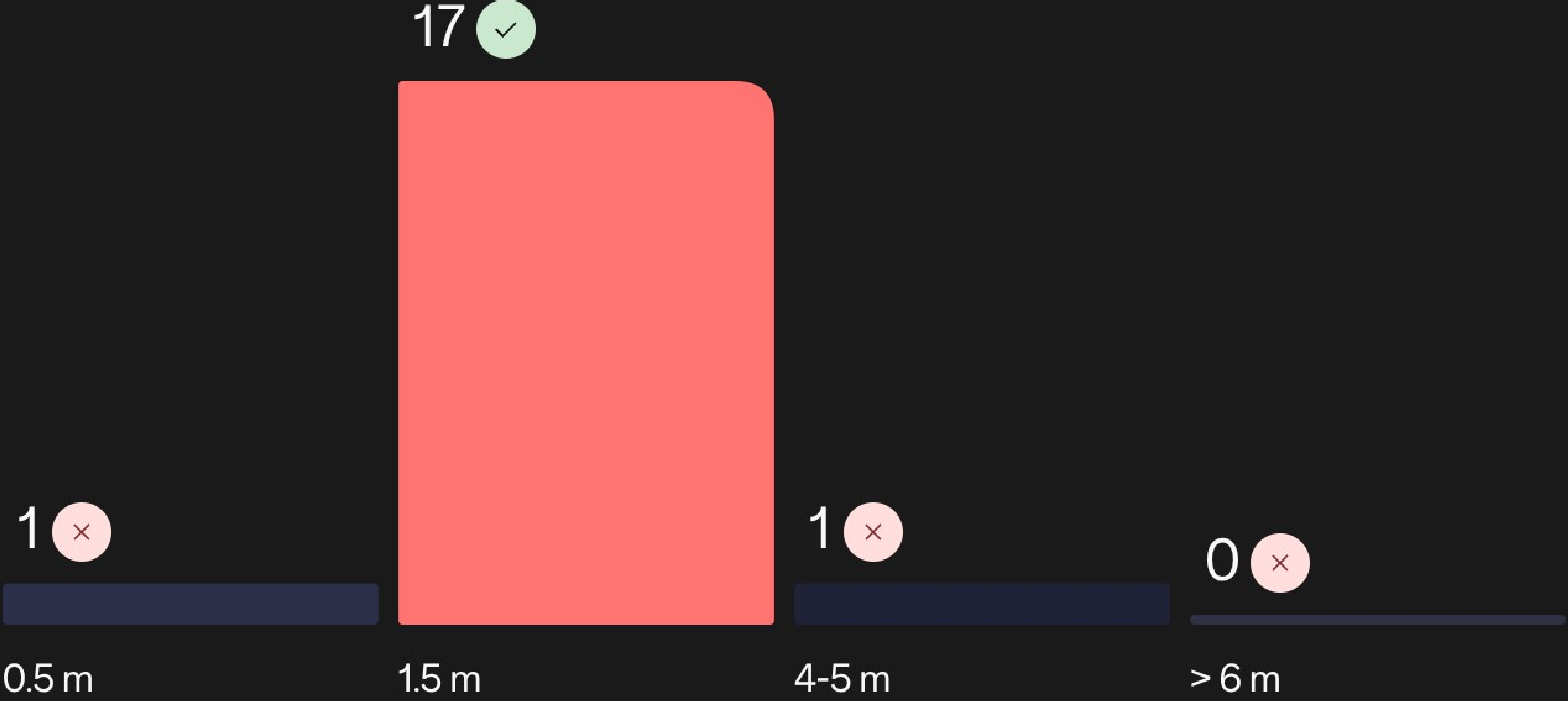
4. What percentage of offshore wind LCOE is typically due to O&M costs?



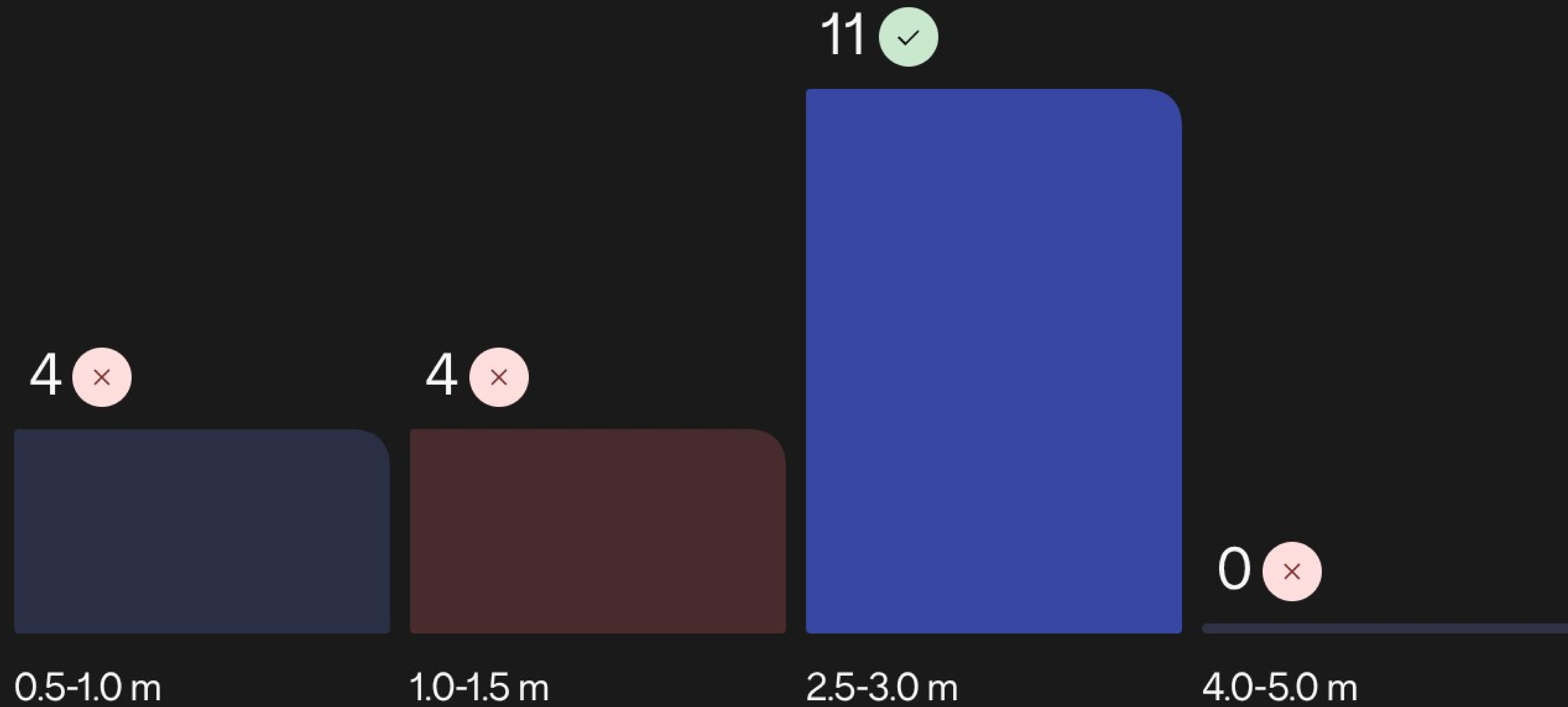
5 Which factor *most* limits vessel operations in winter months in the North Sea?



6. What is the maximum safe wave height for crew transfer using a Crew Transfer Vessel (CTV)?



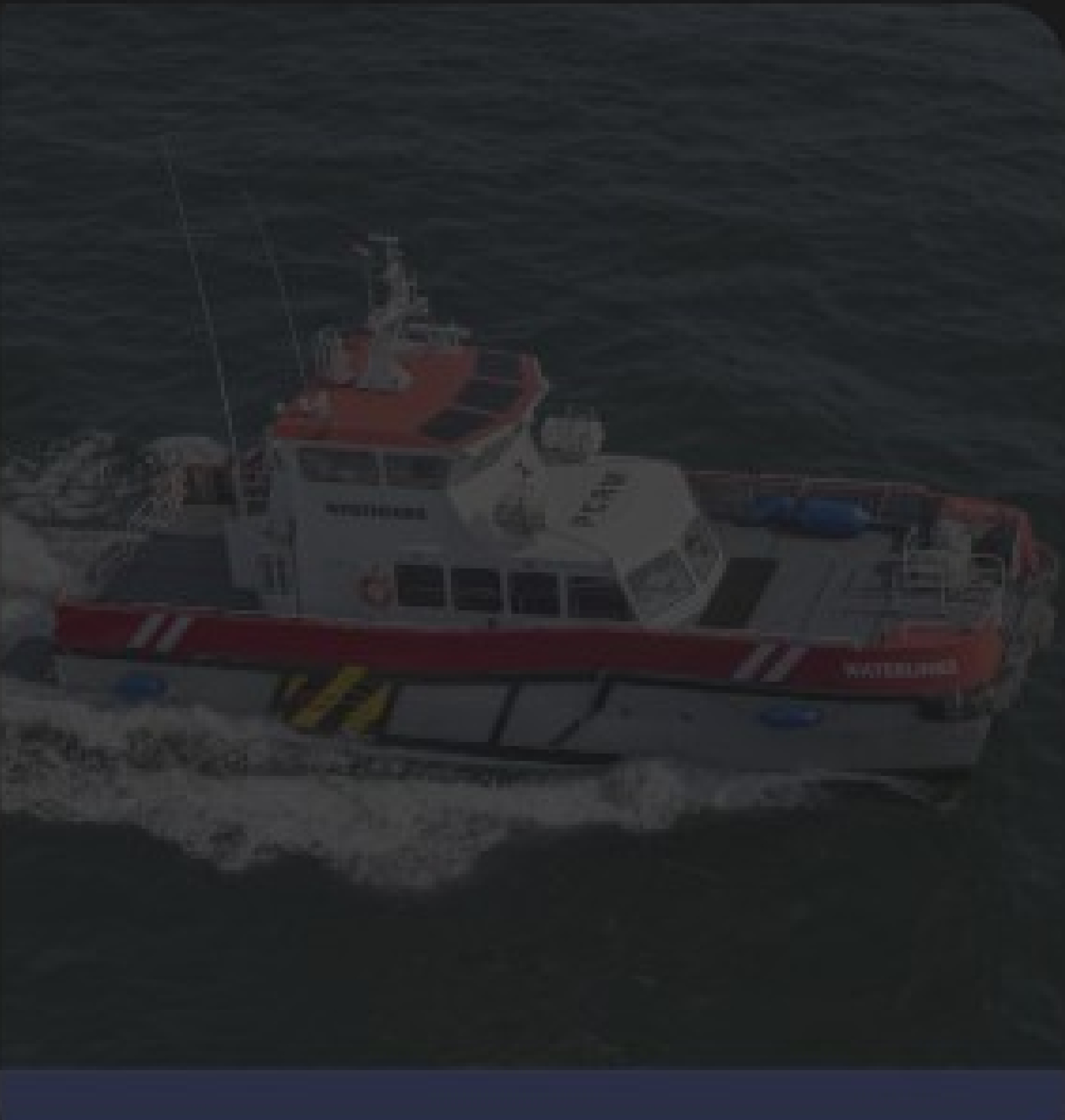



7. What is the maximum safe wave height for crew transfer using a Service Operation Vessel (SOV)?



8. Which of these weather factors is *least* relevant for offshore vessel accessibility?



9. Which type of vessel is typically use for heavy-lift operation (e.g. full wind turbine blade replacement) ?

<p>1 ✘</p> 	<p>0 ✘</p> 	<p>18 ✔</p> 	<p>2 ✘</p> 
<p>Crew Transfer Vessel (CTV)</p>	<p>Service Operation Vessel (SOV)</p>	<p>Jack-Up Crane Vessel (JUV)</p>	<p>Feeder Vessel</p>

10. What is the main reason **SOV** are often preferred for far-from-shore wind farms O&M than CTV?



What information do you need to estimate the O&M cost?

Distance to shore

weather conditions

turbine age

Radius of the turbine

O&M duration

Distance to shore,
weather window, vessel
information

worker availability

Staff costs

What information do you need to estimate the O&M cost?

Failure rate

wave conditions

Failure time

Staff training info

Staff costs

Number of turbines 6

vessel cost and
availability

Workforce, vessel, resources
availability; cost of repairs
and replacements; cost of
maintaining the digital
systems.

What information do you need to estimate the O&M cost?

failure estimation

Turbine size

Duration

Turbine type and
manufacturing

The number of turbines,
distance from
shore/location, maturity of
the wind power plant

Turbine and foundation
types