Improving O&M simulations by integrating vessel motions for floating wind farms

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Outline

- Research objective
- Methodology
- Case study
- Results
- Conclusions

Research objective

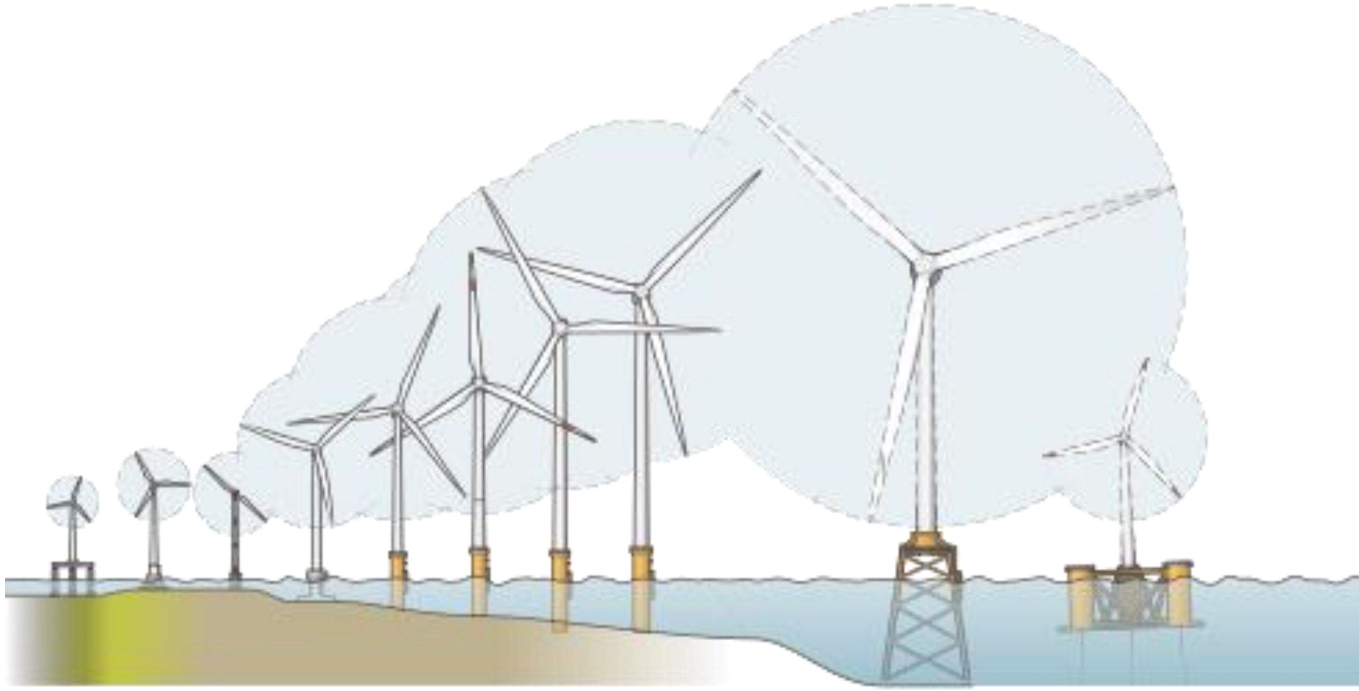
Motivation

EU climate target & FOWT potential

- 55% GHG reduction by 2030[1]
- FOWT can unlock 80% offshore wind potential in deep waters (>50m) [2]

O&M challenges

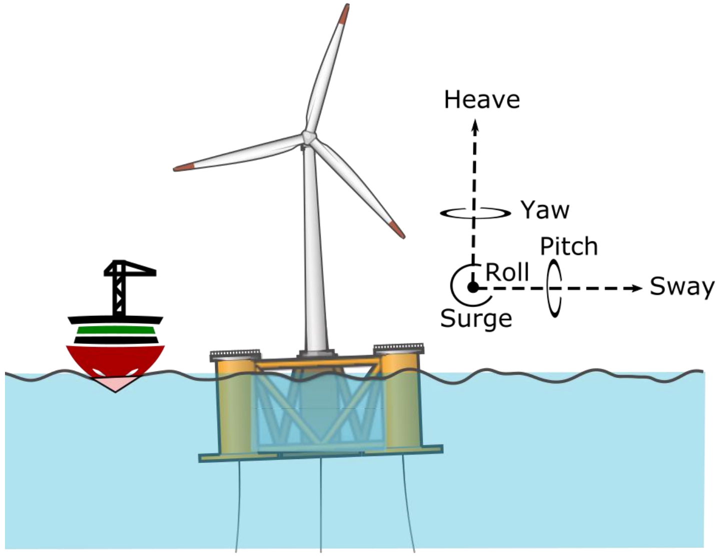
- O&M = 30% of LCOE for FOWT [3]
- High O&M costs linked to Major Component Replacement (MCR)



Evolution of offshore wind energy

Research objective

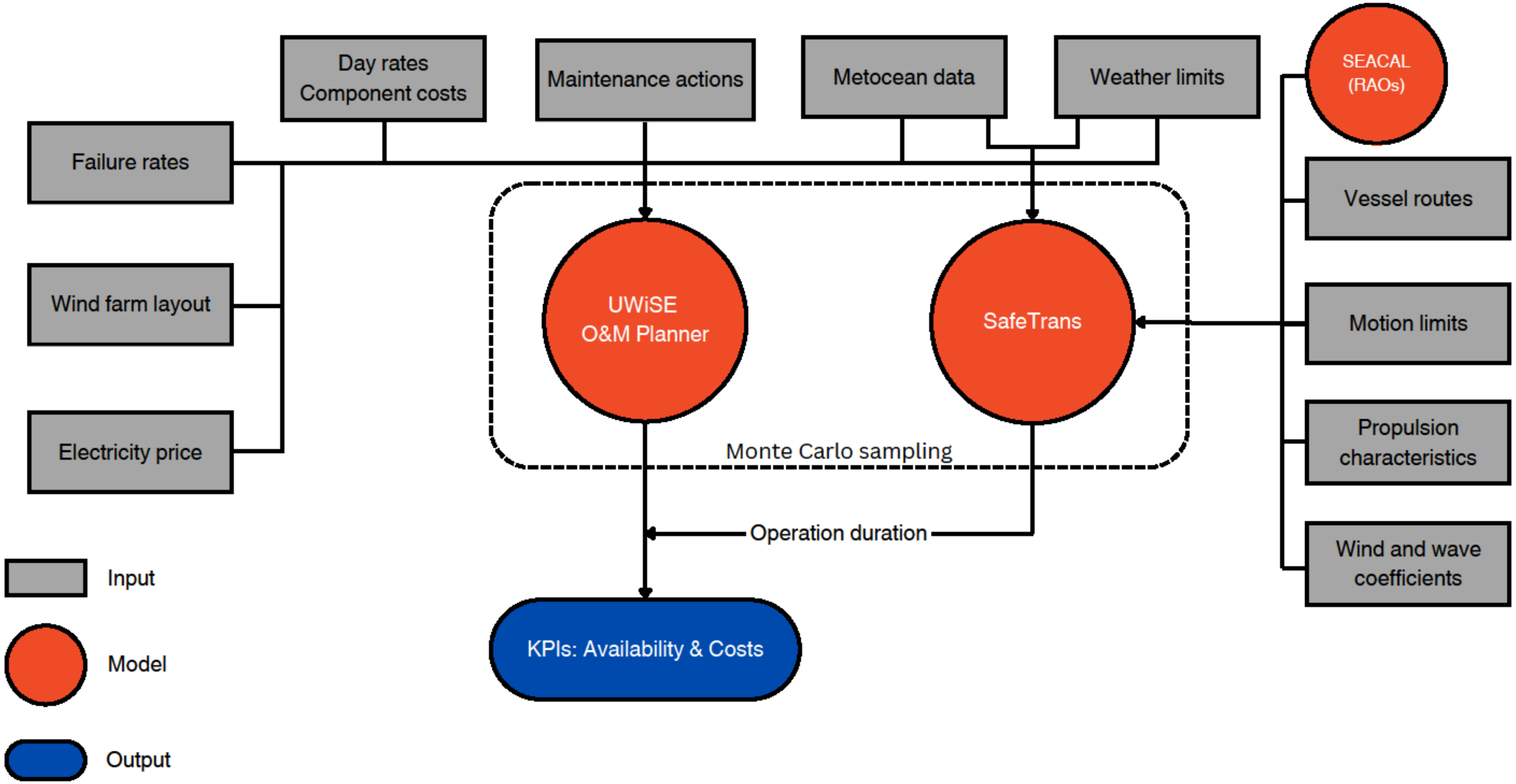
Major component replacement (MCR) in floating wind involves replacing critical turbine or platform components with specialized tools and planning to minimize downtime.



Research question: How can current O&M models be adapted to incorporate dynamic motion parameters for a more accurate evaluation of FOWT operations?

Methodology

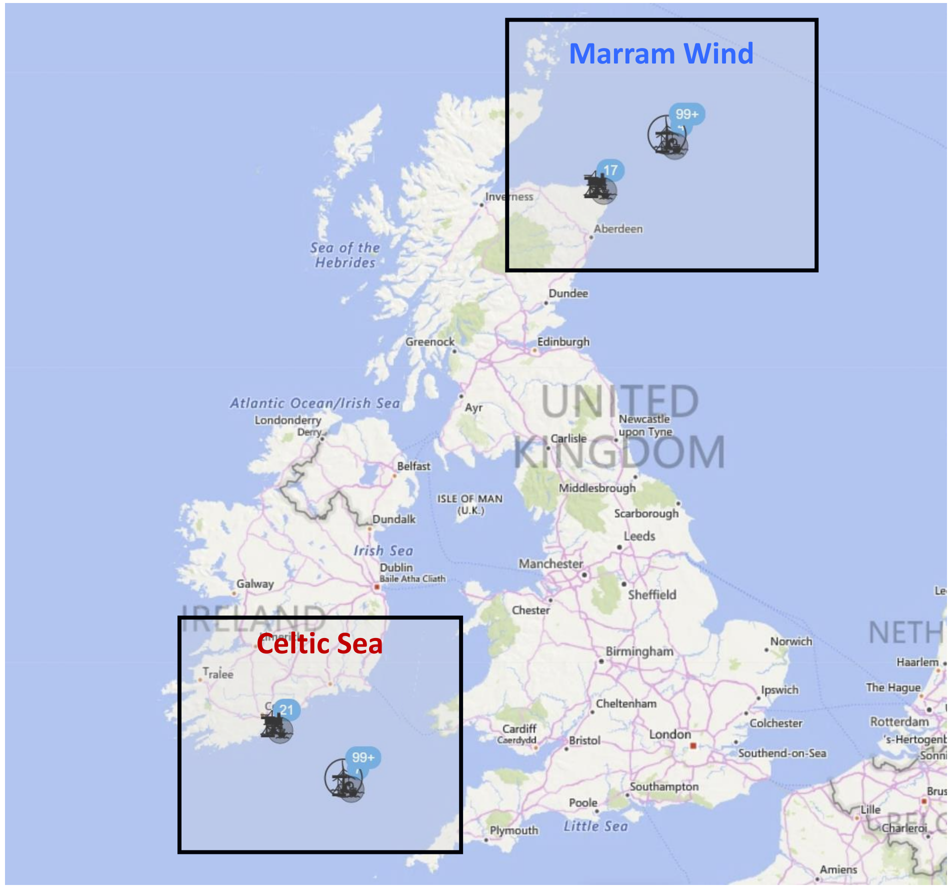
Methodology



[4, 5]

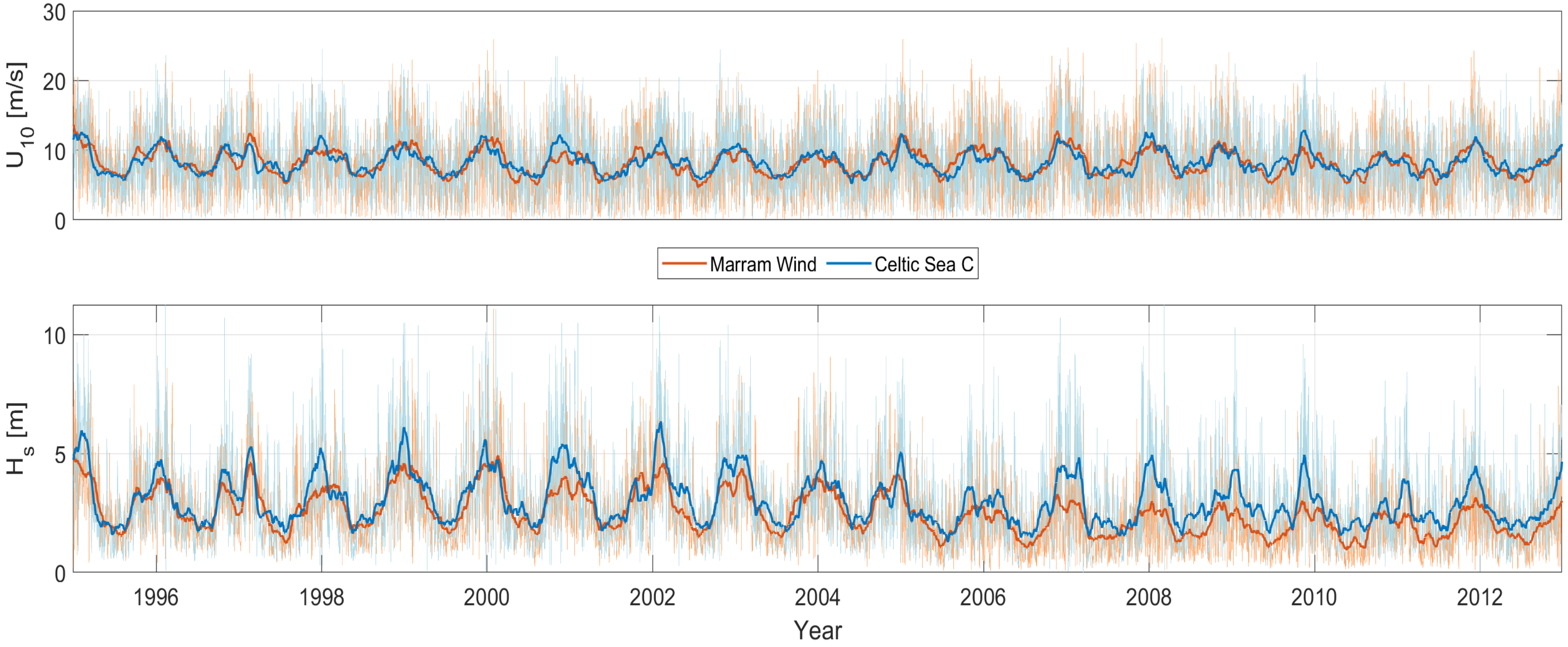
Case study

Reference wind farm sites



	Wind Farm Characteristics	
Farm Layout	100 x 15MW	
Floater Type	Semi-Submersible	
Turbine	15 MW NREL turbine (Direct drive)	
Lifetime	25 years	
Location	North Sea: Marram Wind	Celtic Sea: Celtic Sea C
Water Depth	87 - 117.5 m	90 – 100 m
Port	Fraserburght	Loughbeg
Distance to Port	96.83 km	129.66 km
O&M Stretegy	SOV-based	

Metocean data



Time series plots of mean wind speed (U_{10}) and significant wave height (H_s) for Marram Wind and Celtic Sea C, showing raw data (lighter shades) and moving averages (darker lines) calculated with a bin size of 1000.

Vessel and reliability data

Vessel Characteristics							
Vessel	D/W Rate	M/D Rate	L_{PP} [m]	T [m]	Δ [tons]	T_B [tons]	V_s [kts]
SOV (ROV Supported)	75,000	225,000	84	5.0	6245	73	11.2
AHT (CTV Assisted)	66,000	530,000	88	7.3	7354	250	19.3
AHT	55,000	500,000	88	7.3	7354	250	19.3
Lead Tug Vessel	30,000	200,000	88	7.3	7354	250	19.3 *
Assist Tug Vessel	30,000	200,000	49.5	5.1	2290	100	9.8
SHC assist Tug Vessel	20,000	150,000	49.5	5.1	2290	100	9.8
SSCV, operational	290,000	325,000	120	22.5	49,956	700	0.0
SSCV, transit	290,000	325,000	120	6.67	20,959	700	8.0
SHC platform, transit	80,000	160,000	60	3.33	3947	-	6.8 *
Onshore crane	25,000	185,000	-	-	-	-	-

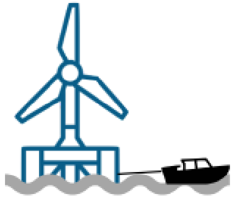
Vessel characteristics including day/wait rates, mobilization/demobilization rates, dimensions, draft, displacement, bollard pull, and speed.

O&M characteristics					
Component	Maintenance	Failure rate	Cost (€)	Duration (hrs.)	Resources
Corrective Maintenance					
Direct Drive Generator	MCR	0.009	236,500	81	2 Tugs + AHT + 8T
	MR	0.03	14,340	25	SOV + 3T
	mR	0.546	1000	7	SOV + 2T
Power Converter	MCR	0.077	55,000	57	2 Tugs + AHT + 4T
	MR	0.338	7000	14	SOV + 3T
	mR	0.538	1000	7	SOV + 2T
Main Shaft	MCR	0.009	232,000	48	2 Tugs + AHT + 5T
	MR	0.026	14,000	18	SOV + 3T
	mR	0.231	1000	5	SOV + 2T
Power Electrical System	MCR	0.002	50,000	18	2 Tugs + AHT + 4T
	MR	0.016	5000	14	SOV + 3T
	mR	0.358	1000	5	SOV + 2T
Yaw System	MCR	0.001	12,500	49	2 Tugs + AHT + 5T
	MR	0.006	3000	20	SOV + 3T
	mR	0.162	500	5	SOV + 2T
Pitch System	MCR	0.001	14,000	25	2 Tugs + AHT + 4T
	MR	0.179	1900	19	SOV + 3T
	mR	0.824	500	9	SOV + 2T
Blades	MCR	0.001	445,000	288	2 Tugs + AHT + 21T
	MR	0.010	43,110	21	SOV + 3T
	mR	0.456	5000	9	SOV + 2T
Active Ballast System	mR	0.010	1000	8	SOV + 2T
Mooring Lines	MCR	0.013	135,000	360	AHT + CTV + 10T
	MR	0.015	20,000	240	AHT + CTV + 10T
	mR	0.120	1500	40	SOV + 5T
Anchors	MCR	0.013	512,000	360	AHT + CTV + 10T
	MR	0.015	75,000	240	AHT + CTV + 10T
Inter Array Cable	MCR	0.016	220,000	360	SOV + 10T
	MR	0.025	30,000	240	SOV + 10T
Buoyancy Modules	MCR	0.033	100,000	40	SOV + 5T
Export Cable	MR	0.020	30,000	60	SOV + 5T
Preventive Maintenance					
WTG	AC	1	1500	24	SOV + 3T
Platform	AC (topside)	1	600	24	SOV + 4T
	AC (underwater)	0.5	1000	12	SOV + 10T

Component-wise O&M overview detailing frequency, duration, and resource requirements.

Strategy 1: Tow-to-Port

- **T2P Process**: Involves disconnecting, towing FOWT to port, replacing components with onshore cranes, and reconnecting offshore.
- **Resources**: Requires lead/assist tugs, onshore cranes, technicians.
- **Operational Limits**: Governed by weather (wave height, wind speed) and motion criteria (vessel acceleration, roll, pitch).

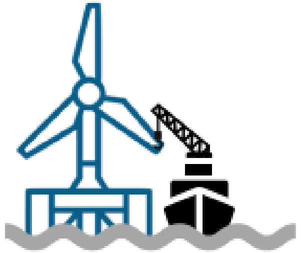


Vessels	Action	Duration (h)	Weather Limits $[H_s^*, U_{10}]$	Motion Limits
Lead tug + Assist tug + Onshore crane	Mobilize vessels	24	-	-
	Transfer technicians	1	-	-
	Transit to site	distance/ vessel speed	[3, 12]	C1
	Turn off WT	-	-	-
	Couple with WT	8	[1.75, 15]	C1
	Disconnect MLs & IACs + joint IACs	60	[1.75, 15]	C1
	Tow WT to port	distance/ towing speed	[3, 12]	C1 + C2
	Quayside operation	6	-	-
	Replace component	MCR (hrs.) component	-	-
	Test & check WT	3	-	-
	Couple with WT	8	[1.75, 15]	C1
	Quayside operation	6	-	-
	Tow WT to site	distance/ towing speed	[3, 12]	C1 + C2
	Dejoint IACs	12	[1.75, 15]	C1
	Reconnect MLs & IACs	60	[1.75, 15]	C1
	WT pre run	4	-	-
	Turn on WT	-	-	-
	Transit to port	distance/ vessel speed	[3, 12]	C1
	Transfer technicians	1	-	-
	Demobilize vessels	24	-	-

Criteria	Response	RMS Limit	Unit
Vessel motion limits at CoG [C1]	Surge acc. (X_a)	1.3	m/s²
	Sway acc. (Y_a)	1.3	m/s²
	Heave acc. (Z_a)	1.9	m/s²
	Roll (ϕ)	6	deg
Towing limits at WT's nacelle [C2]	Surge acc. (X_a)	1.96	m/s²
	Sway acc. (Y_a)	1.96	m/s²
	Roll (ϕ)	5	deg
	Pitch (θ)	5	deg

Strategy 2: Floating-to-Floating

- **FTF Process**: MCR is conducted on-site using an SSCV with a dynamic positioning system and motion-compensating crane.
- **Resources**: Requires a semi-submersible SSCV, onboard crane, technicians, and advanced motion compensation systems.
- **Operational Limits**: Governed by vessel motion at the center of gravity and nacelle, with higher weather tolerances than T2P due to SSCV's seakeeping capabilities.

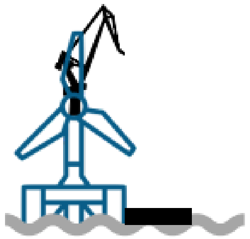


Vessels	Action	Duration (h)	Weather limits [H_s^*, U_{10}]	Motion Limits
SSCV	Mobilize vessel	24	-	-
	Transfer technicians component	4	-	-
	Transit to site	distance/speed	[4.5, 15]	C1
	Turn off WT	-	-	-
	Ballast to draft & deploy crane	4	[3.5, 15]	C1
	Replace component	MCR (hrs.) × 1.2	[3.5, 15]	C1 + C3
	WT pre run	4	-	-
	Turn on WT	-	-	-
	Transit to port	distance/speed	[4.5, 15]	C1
	Transfer technicians component	4	-	-
	Demobilize vessels	24	-	-

Criteria	Response	RMS Limit	Unit
Vessel motion limits at CoG [C1]	Surge acc. (X_a)	1.3	m/s²
	Sway acc. (Y_a)	1.3	m/s²
	Heave acc. (Z_a)	1.9	m/s²
	Roll (ϕ)	6	deg
Floating to floating limits at nacelle [C3]	Surge (X)	1.5	m
	Sway (Y)	1.5	m
	Heave (Z)	0.4	m

Strategy 3: Self hoisting cranes

- **SHC Process**: MCR is conducted on-site using a self-hoisting crane integrated with the FOWT, mitigating relative motions during lifting.
- **Resources**: Requires a self-hoisting crane platform, small tug, CTV, and technicians for on-site component replacement.
- **Operational Limits**: Governed by weather and heave motion at the SHC platform deck, with active compensation systems ensuring safe lifting.



Vessels	Action	Duration (h)	Weather Limits [H_s^*, U_{10}]	Motion Limits
CTV + Small tug + Self-Hoisting Crane	Mobilize vessel	24	-	-
	Transfer technicians and component	4	-	-
	Tow SHC platform to site	distance/speed	[3,15]	C1
	Turn off WT	-	-	-
	Couple SHC platform to WT	1	[2, 15]	-
	Install crane from platform to tower	3	[3.5, 15]	-
	Replace component	MCR (hrs.) × 1.2	[3.5, 15]	C4
	Lower crane and preparation	3	[3.5, 15]	-
	Decouple SHC platform from WT	1	[2, 15]	-
	Turn on WT	-	-	-
	Tow SHC platform to port	distance/speed	[3,15]	C1
	Transfer technicians and component	4	-	-
	Demobilize vessels	24	-	-

Criteria	Response	RMS Limit	Unit
Vessel motion limits at CoG [C1]	Surge acc. (X_a)	1.3	m/s²
	Sway acc. (Y_a)	1.3	m/s²
	Heave acc. (Z_a)	1.9	m/s²
	Roll (ϕ)	6	deg
Motion criteria at SHC platform deck [C4]	Heave (Z)	0.4	m

Results

Key performance indicators

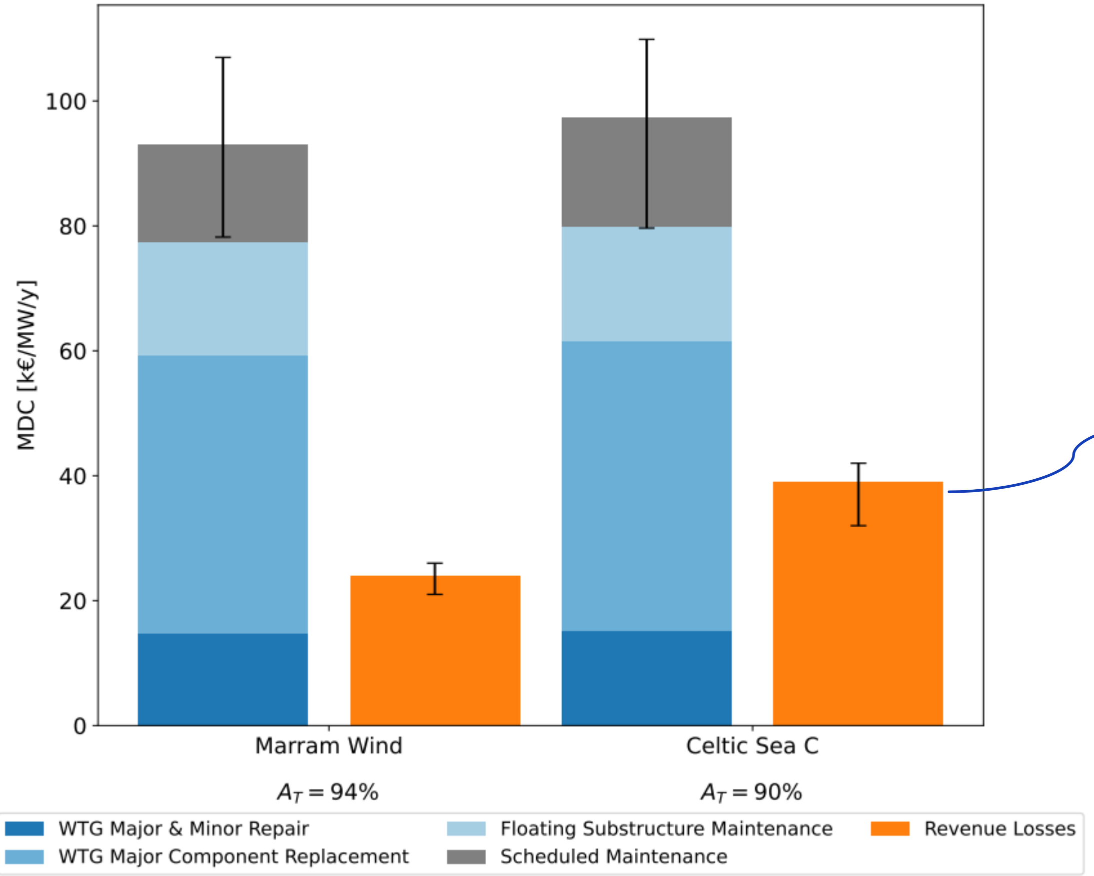
Maintenance and Downtime Cost (MDC): Represents O&M costs and revenue losses in k€/MW/year, providing a clear financial impact of maintenance activities.

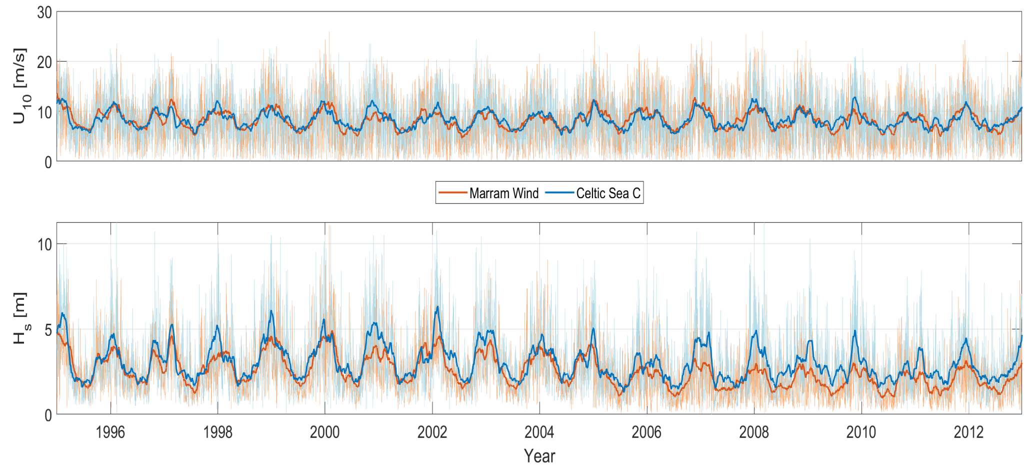
$$\text{MDC} = \frac{\sum_{i=1}^{n} (C_{v,i} + C_{t,i} + C_{s,i} + L_{r,i})}{\text{MW} \cdot \text{year}}$$

Time-based Availability (A_T) [%]: Reflects the percentage of operational time relative to total hours, indicating wind farm efficiency.

$$A_T = \frac{T_o}{T_t} \times 100$$

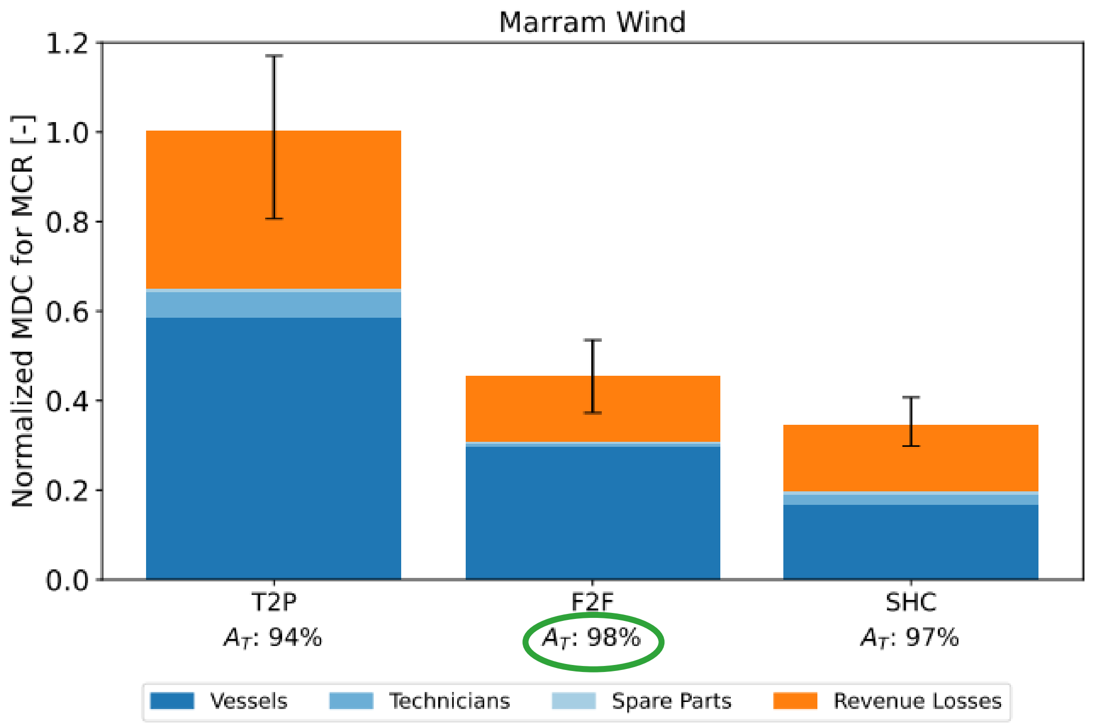
Tow-to-Port strategy

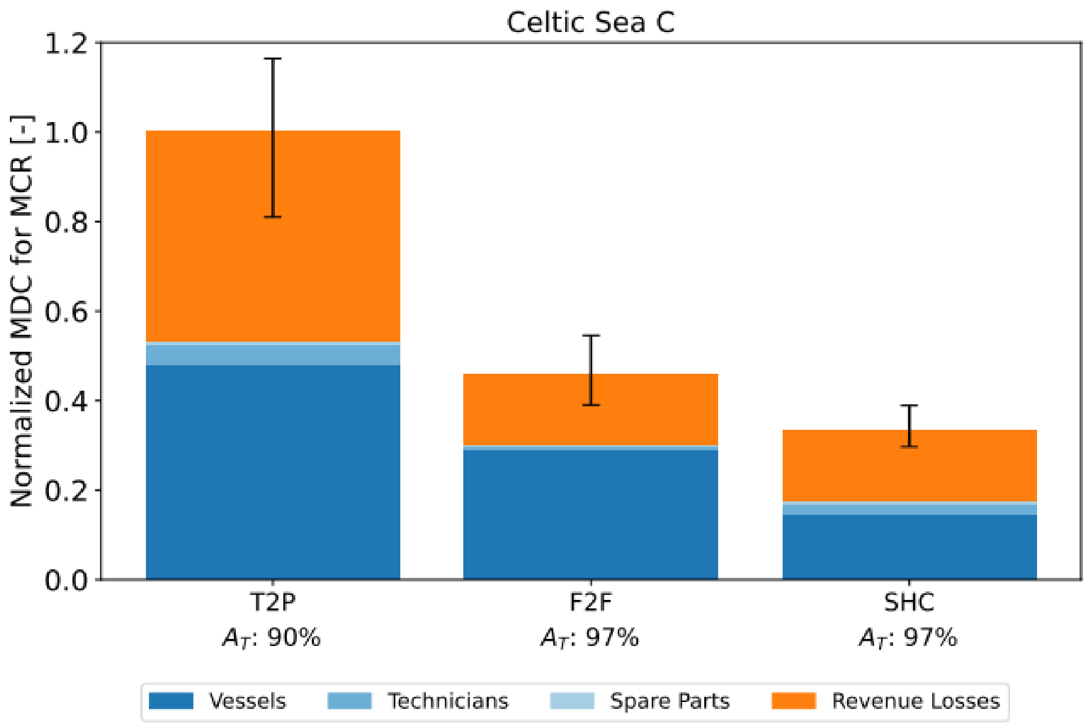




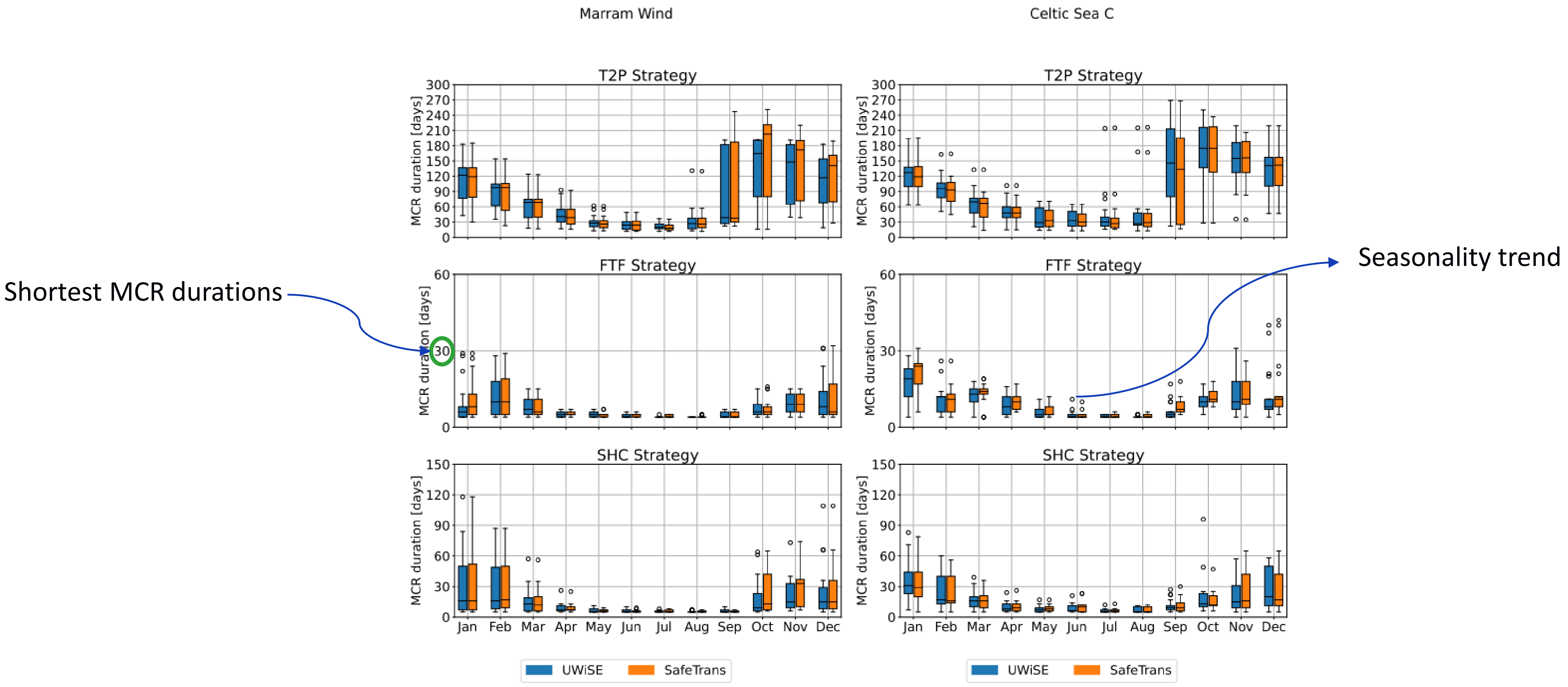
H_s is significantly higher at Celtic Sea

Comparison of MCR strategies

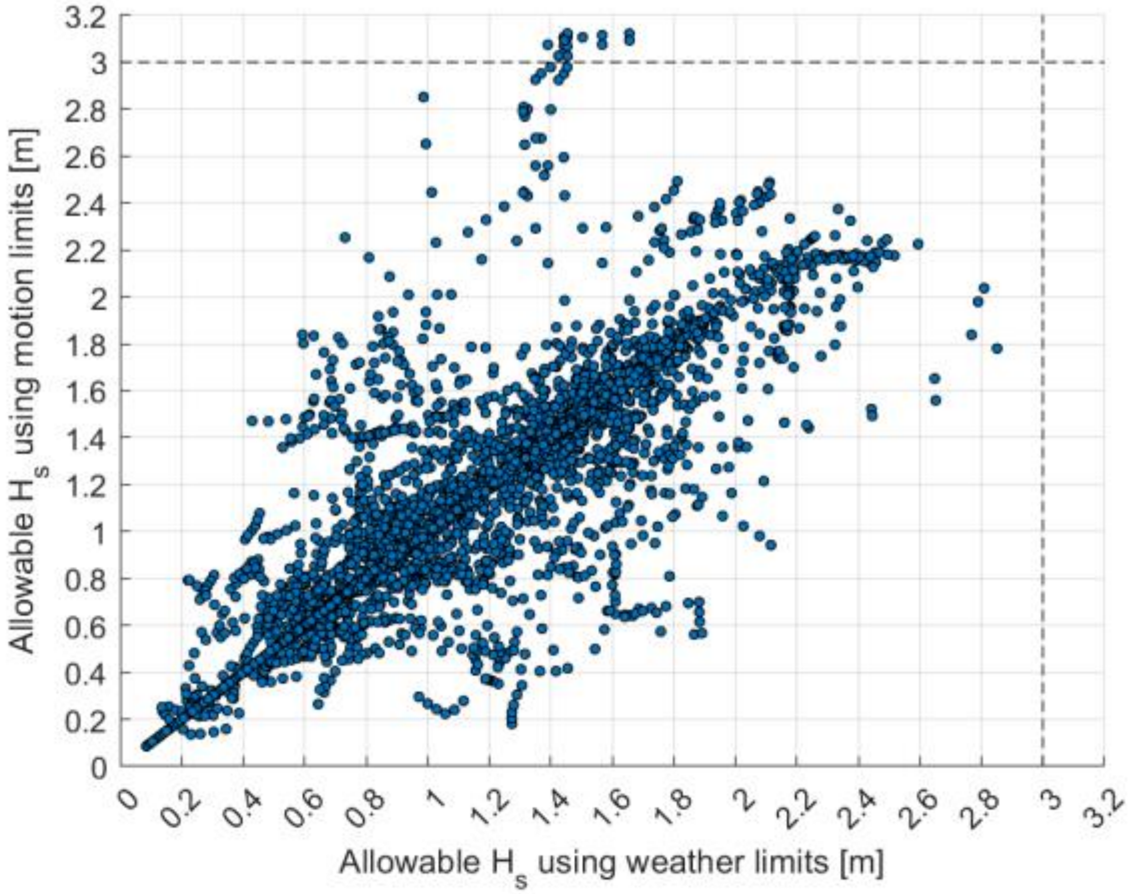




Comparison of MCR strategies



Motion limits in O&M simulations



- **Comparison**: "Tow WT to Port" modeled with static limits and motion limits.
- **Key Difference**: Incorporating motion limits allows higher H_s(>3 m) by considering vessel dynamics, while fixed conservative limits are seen when using static limits.

Conclusions

Conclusions

- **Integrated Methodology**: Combines motion-based operational limits using SafeTrans with UWiSE for realistic O&M cost and downtime assessments.
- **Performance Insights**: SHC strategy achieves the lowest MDC costs, while F2F strategy offers the highest availability.
- **Tool Comparison**: Motion-based methodology utilizes realistic operational limits tailored to the FOWT market, offering more applicable assessments than static, conservative limits.

Future works:
- **Availability Constraints**: Model vessel and spare part availability to reflect real-world limitations.
- **GHG Emissions**: Quantify emissions to evaluate environmental impacts of O&M activities.

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Know more about the project?

Methodology