Task49 浮体式洋上風力発電所の統合設計
Integrated Design on Floating wind Arrays (IDeA)

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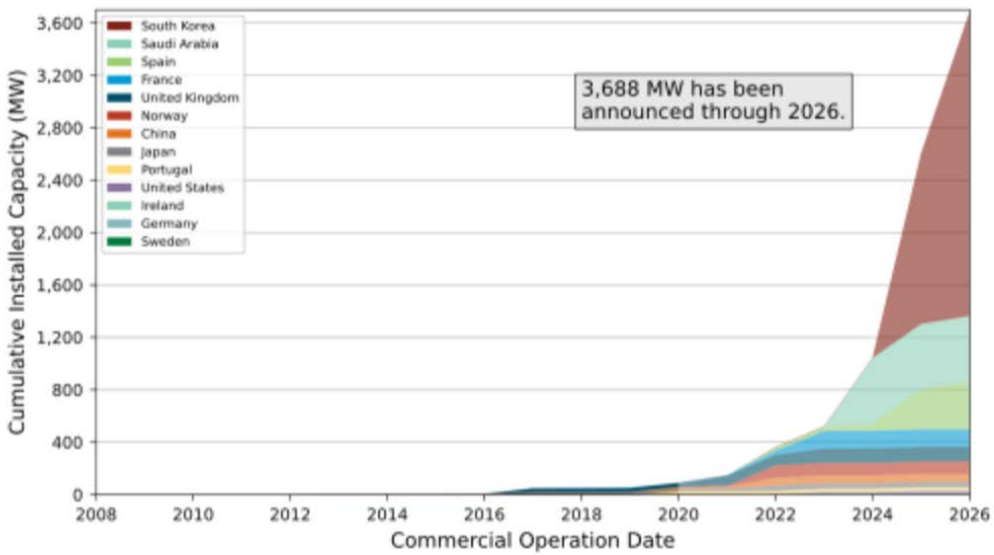
Task49 の目的

- 浮体式洋上風力発電所は2020年現在、世界で79MWが運転しているに過ぎないが、今後10年間で飛躍的な増大が期待されている。



Musiel et al., (2021)

- Task49は、世界各国における浮体式洋上風力発電所の最適設計に資するため、標準的な浮体式洋上風力発電所を定義し、標準的な設計手法の枠組および設計ツールを開発する。

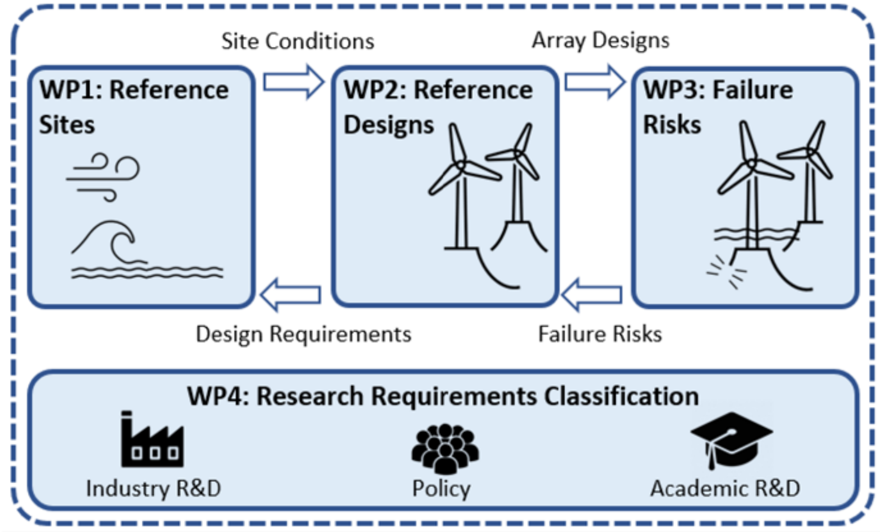
Task49 ワークパッケージ

- WP1：標準設計条件の定義
  世界各国の観測データ、シミュレーションデータを元に、標準設計条件を定義する。

- WP2：標準発電所(Array)の定義
  風車配置、ユニット(風車-浮体)、係留方法、送電ケーブル、変電所、等を含む標準浮体式風力発電所を定義する。

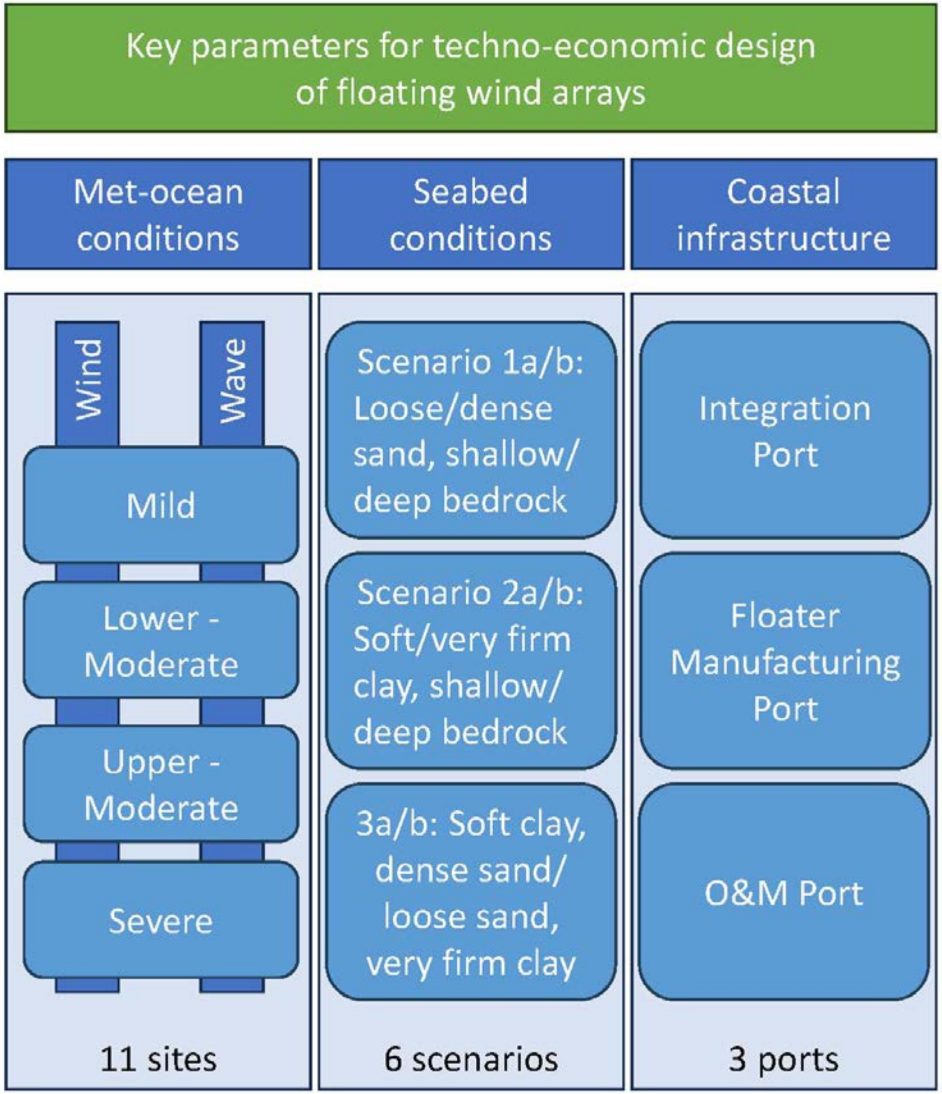
- WP3：発電所レベルでの損傷リスクと低減
  発電所レベルでの損傷モードを明らかにし、その影響を明らかにする。

- WP4：問題点の明確化
  各ワークパッケージにおける問題点を明らかにし、今後の研究課題を明らかにする。



WP1 標準設計条件の定義

- 気象海象条件
- 海底地盤条件
- 沿岸インフラ
- 環境影響
- 社会･経済影響
- 規制と許認可

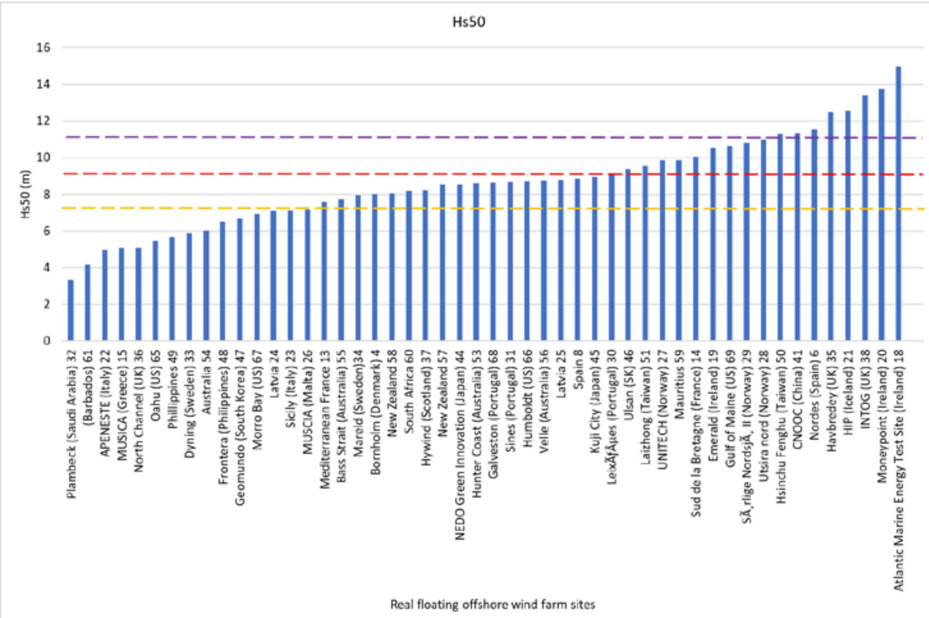


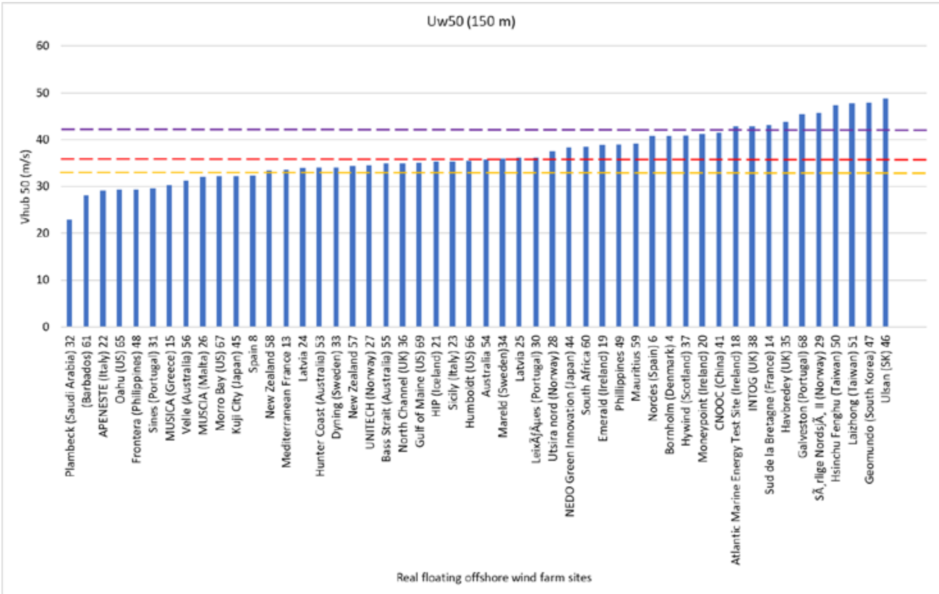
気象･海象条件の分類

- 全世界69サイトにおいて、ERA5再解析データ(気象：0.25度解像度；海象0.5度解像度)の生データを用いて、風速と波浪の極値を推定した。

- 各サイトの水深をGEBCO(GEneral Bathymetric Chart of the Oceans)データから抽出。

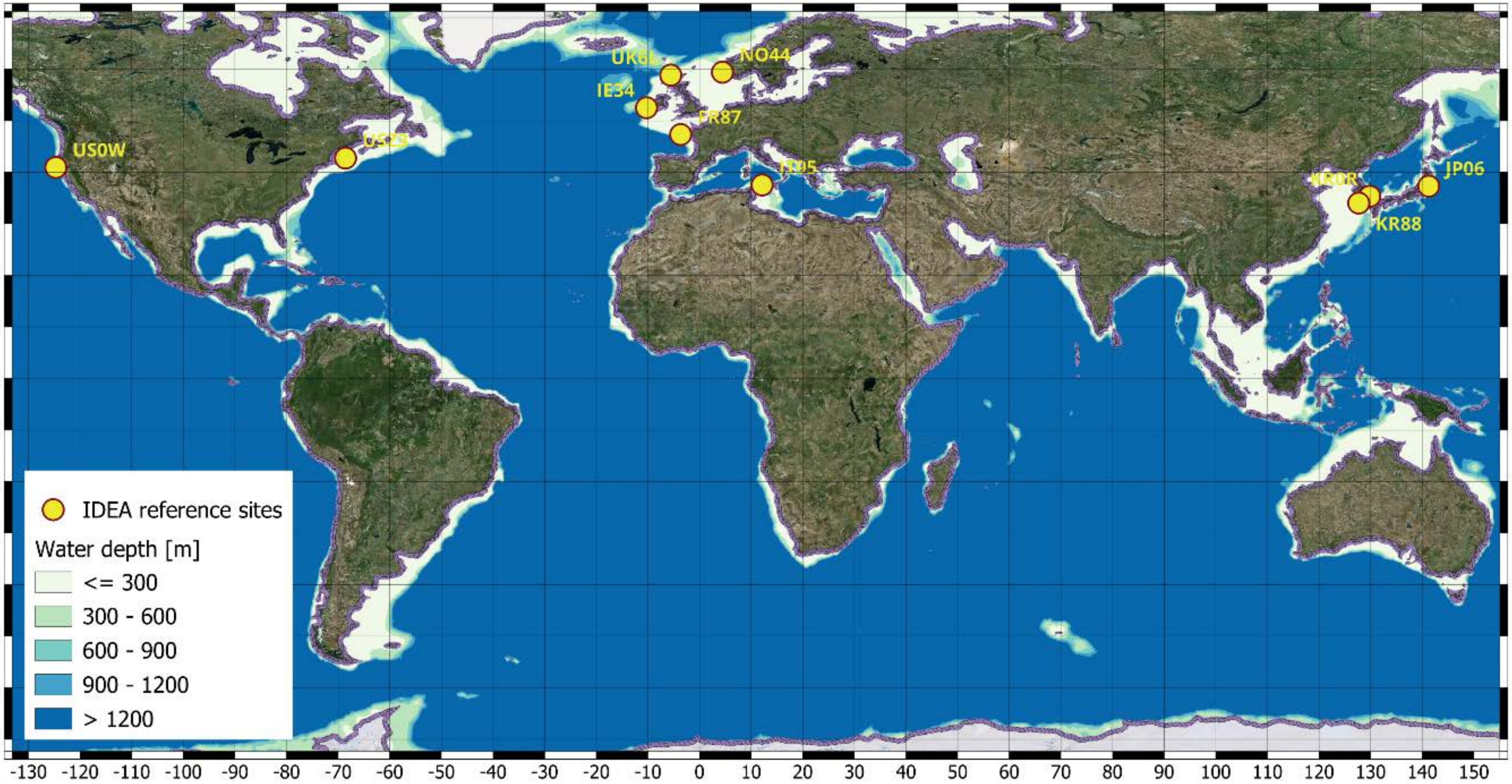
49サイトの極値の分類





Severity	Wind threshold (m/s)	Wave threshold (m)
Mild	< 33	< 7.5
Lower Moderate	33 < 36	7.5 < 9
Upper-Moderate	36 < 42	9 < 11
Severe	> 42	> 11

世界各国のサイトの紹介



サイトデータの例

ID*	Name	Latitude [deg]	Longitude [deg]	Water depth [m]	Distance from shore [km]
IT95	Hannibal	37.536	12.12	-353	35
US0W	Humboldt	40.928	-124.708	-707	43.8
KR0R	Ulsan	35.344722	129.841389	-188	32
IE34	MoneyPoint One	52.519	-10.276	-102	23.4
UK6L	Havbredey	58.84328	-5.580929	-91	41.6
JP06	Fukushima	37.311	141.251	90	19.4
NO44	Utsira Nord	59.411	4.433	-273	42.4
USZ3	Gulf of Maine	42.755	-68.583	-148	138
KR88	Geomundo	34.026	127.7	-70	47
FR87	Sud de la Bretagne II	47.325	-3.659	-94	30.7

WP2：標準風力発電所の考え方

Feature	Greatest Interest	Secondary Interest
Layout	Regular rectangular	Triangular, irregular, optimized
Turbine size	15 MW	~20 MW or a range of sizes (12, 15, 18)
Turbine number	Multiple array sizes in the range of 20-100 turbines	As few as 7-10 turbines
Platform type	Steel semisubmersible	Spars, TLPs, barges, concrete construction
Mooring configuration	All basic types (cat-TLP)	Different rope materials, shared configurations, load reducers, multiple anchor types, seabed dependence
Dynamic Cable Configuration	Lazy wave	Catenary free-hanging, suspended W, etc.
Intra-array cable rating	66 kv and 132 kV	
Depth	Shallow, medium, and deep options	
Misc	Seabed changes and anchor/mooring implications	Substation, cable connections, and export cable

Scenario	Shallow	Intermediate	Deep
Key features	Shallow-water mooring/cabling design challenges and innovations	Seabed feature constraints on anchor positions, and innovations on anchoring	Deep-water constraints on mooring layout and turbine spacing, use of W-shaped cables and deep-water mooring innovations
Design variants (sequential)	V1: uniform *Secondary options*: V2: depth gradient with adapted mooring designs V3: spring option	V1: uniform *Secondary options*: V2: complex seabed, adapted layout and anchor positions V3: shared anchor option V4: cable layout designs	V1: uniform *Secondary options*: V2: depth gradient with adapted layout, moorings, cables V3: shared mooring option V4: TLP option
Metocean	Sørlige Nordsjø II	Utsira Nord	Humboldt
Depth	60 meters (m) *Secondary option*: sloped 40–120 m	300 m *Secondary option*: irregular 200–400 m	800 m *Secondary option*: irregular 600–1,000 m
Seabed	Generic	Generic *Secondary option*: irregular with bedrock/ridges	Generic

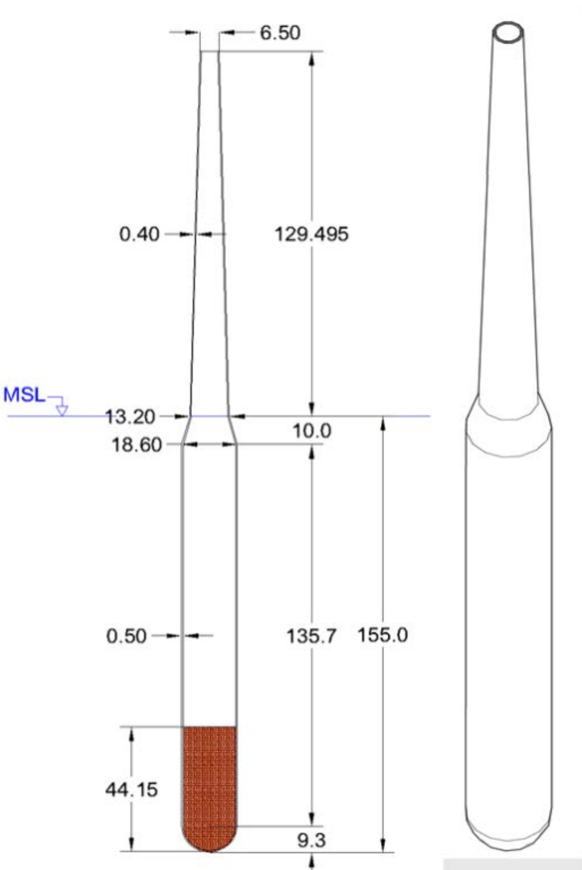
Scenario	Shallow	Intermediate	Deep
Array layout	Rectangular	Rectangular *Secondary option*: varied	Rectangular *Secondary option*: varied
Platform type	Semi	Semi or Spar *Secondary option*: TLP	Semi or Spar *Secondary option*: TLP
Mooring configuration	Semi-taut shallow water	Catenary chain (+wire?) *Secondary option*: semi-taut intermediate water	Taut synthetic *Secondary options*: shared taut, TLP
Mooring layout	Regular	Regular *Secondary option*: varied	Regular
Anchors	Drag embedment *Secondary option*: suction pile	Drag embedment *Secondary option*: shared suction pile	Suction pile *Secondary option*: drag embedment
Cable configuration	Lazy wave	Lazy wave	Fully suspended
Cabling layout	Regular	Regular or irregular if seabed constraints	Regular

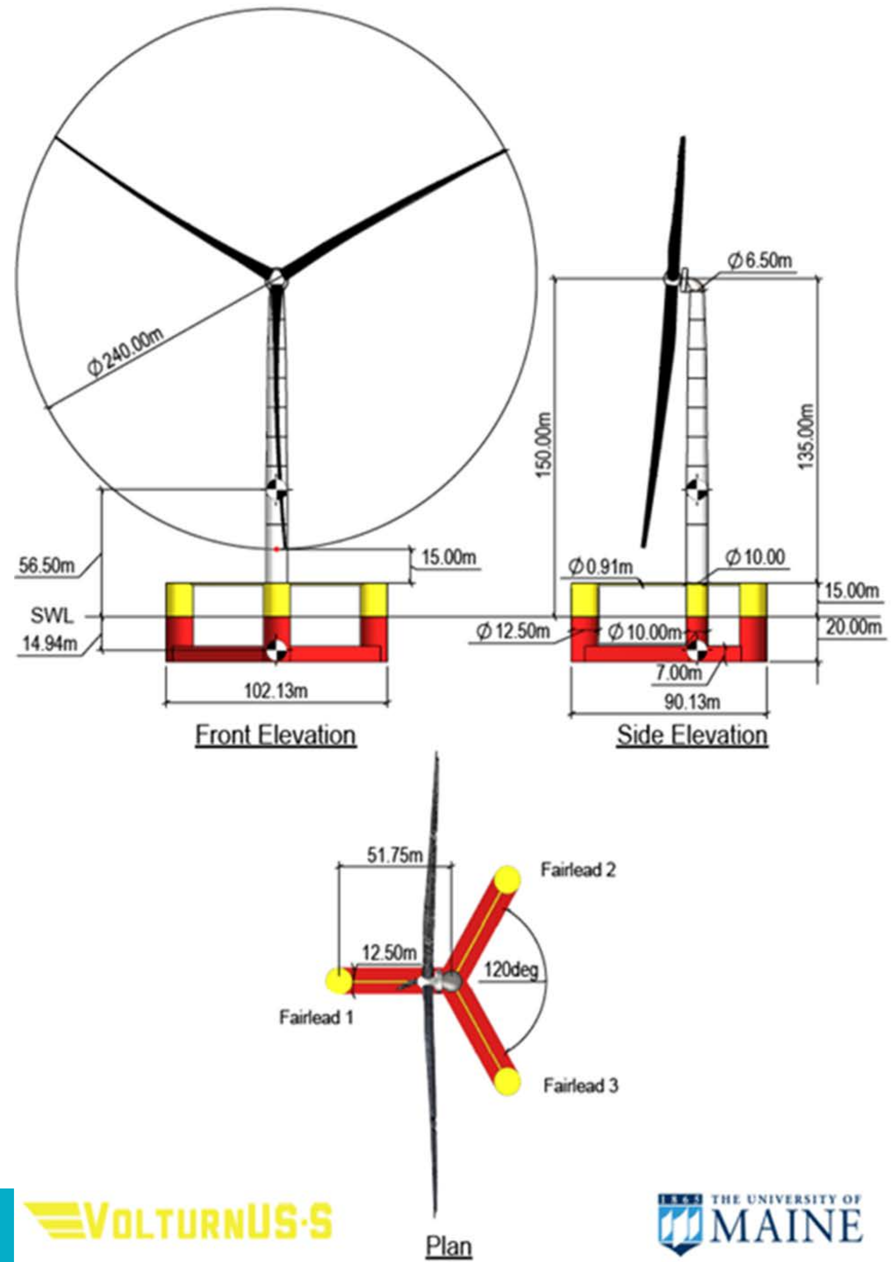
- NREL 5MW, DTU 10MW などいくつかの公的に利用可能な風車モデルがあるが、IEA 15MW (Task37) 風車を標準風車として考える。

Parameter	Value
Power rating (MW)	15
Turbine class	International Electrotechnical Commission (IEC) Class 1B
Specific rating (watts per square meter [W/m^2])	332
Rotor orientation	Upwind
Cut-in wind speed (meters per second [m/s])	3
Rated wind speed (m/s)	10.59
Cut-out wind speed (m/s)	25
Design tip-speed ratio	9
Minimum rotor speed (rpm)	5
Maximum rotor speed (rpm)	7.56
Maximum tip speed (m/s)	95
Rotor diameter (m)	240
Hub height (m)	150
Hub diameter (m)	7.94
Hub overhang (m)	11.35
Rotor precone angle (deg)	-4
Blade prebend (m)	4
Blade mass (tonnes [t])	65
Drivetrain	Direct drive
Shaft tilt angle (deg)	6
Rotor-nacelle assembly mass (t)	1,017

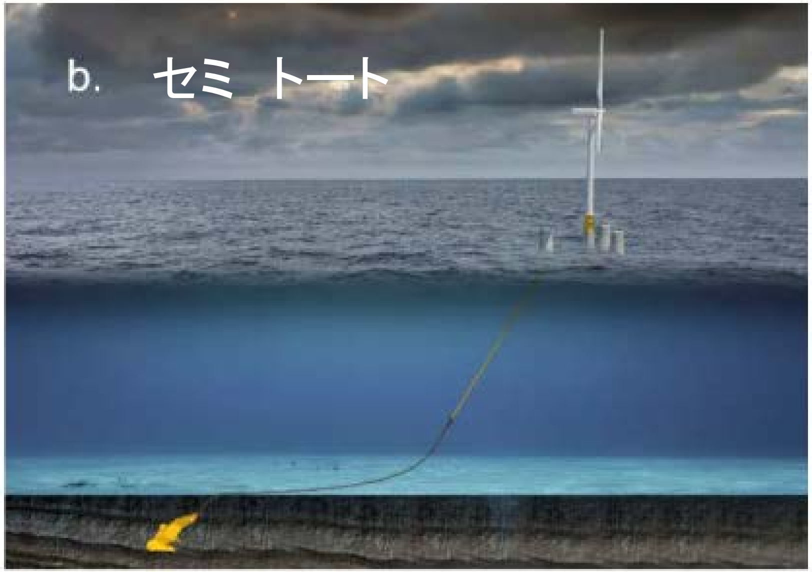
標準浮体

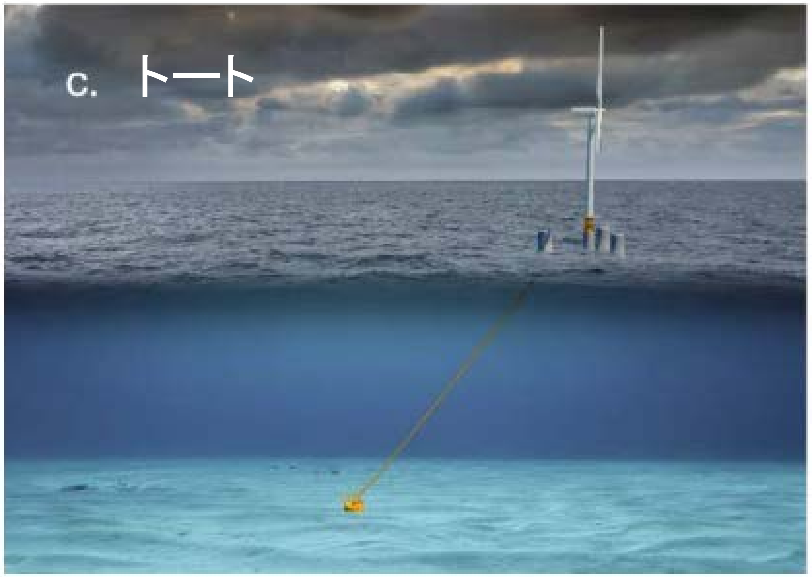
- メイン大学(アメリカ) VolturnUS-S　セミサブ浮体
- カタルーニャ工科大学(スペイン) Wind Create スパー浮体

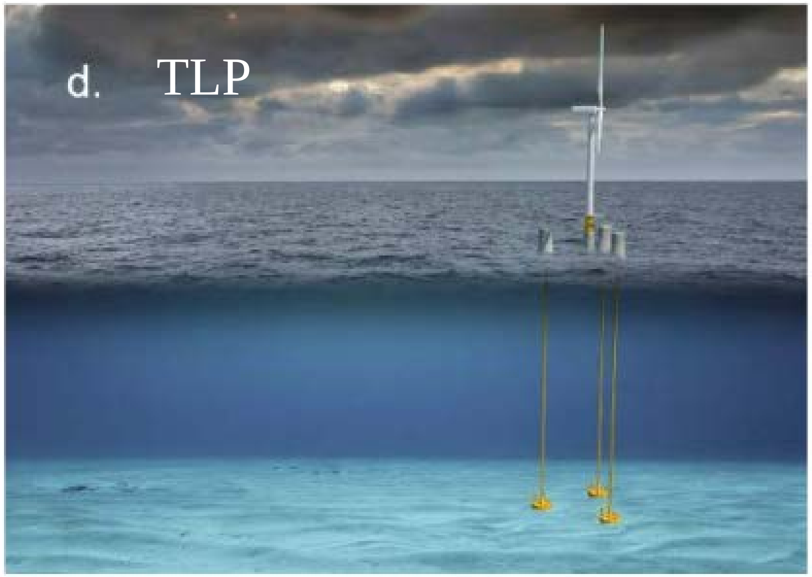




WP2:係留索の種類



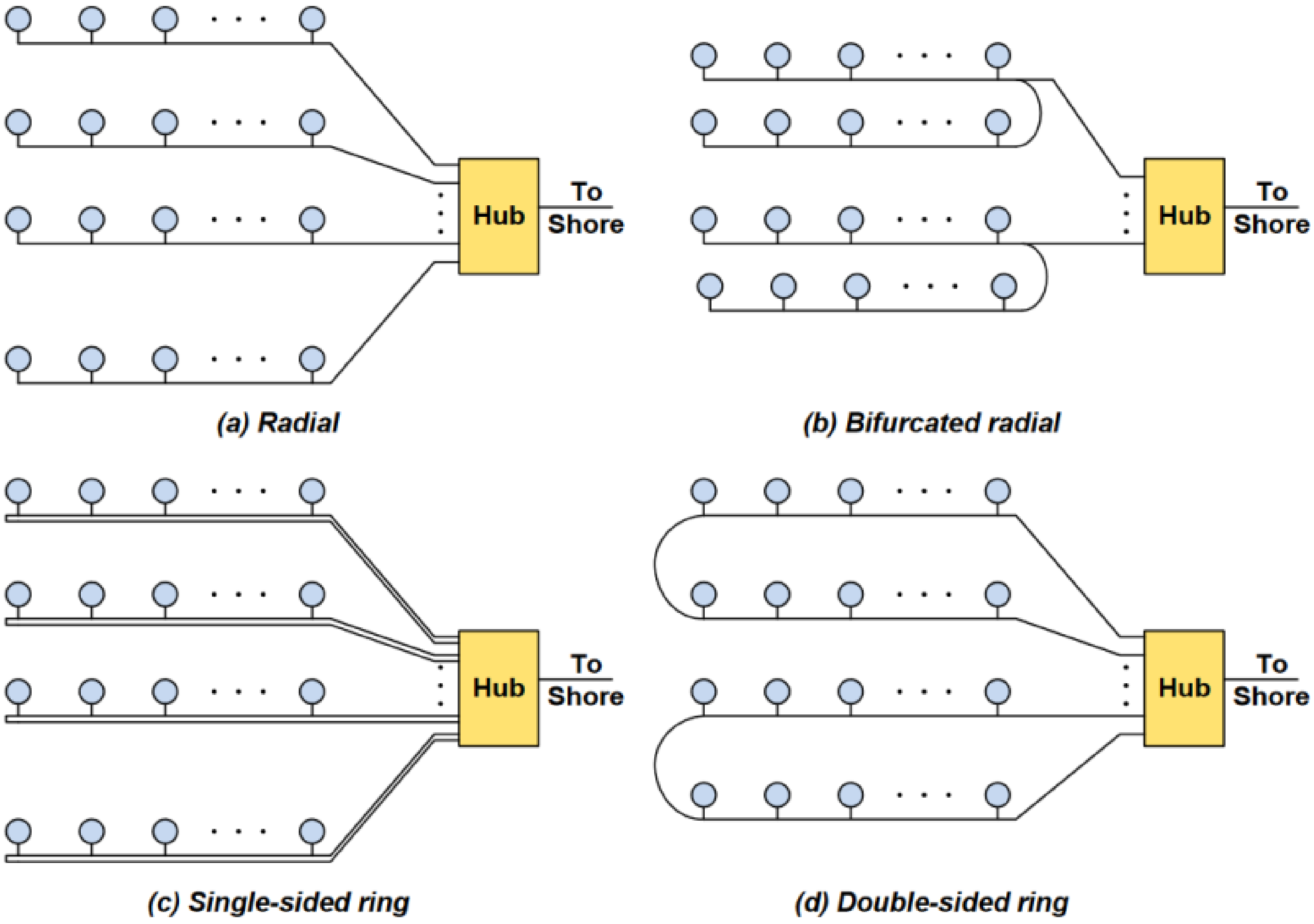




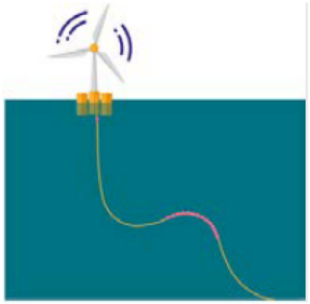
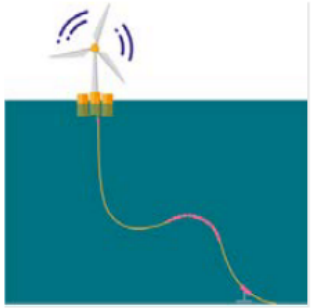
WP2:係留設計ー既存の係留のレビュー

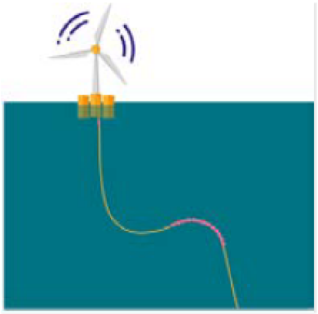
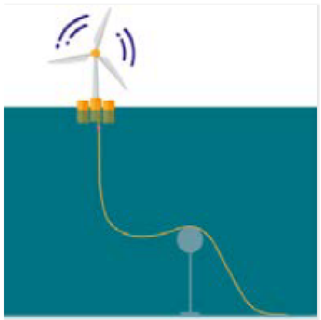
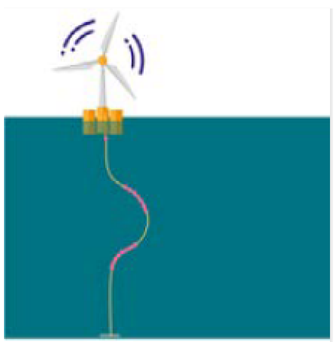
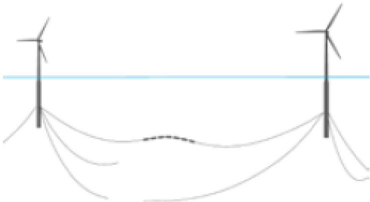
Project	Mooring Arrangement	Mooring Line Configuration	Expected Reasoning
	nylon hawsers and 3 semi-taut mooring lines	hawsers tether the platform to the single-point, 3 semi-taut mooring lines connect to suction pile anchors	turbine to weathervane with the wind and allows a single point of mooring/cable disconnection for marine operations
FloatGen	6 mooring lines made of synthetic fiber (nylon)	Nylon mooring lines with chain segments at the anchor and fairlead	Nylon absorbs wave-induced platform motions, has adequate fatigue performance, and does not corrode. Chain length was minimized to minimize the mooring radius. Use of chain near the seabed avoids rope chafing degradation at the seabed.
Provence Grand Large	TLP with 3 double tension legs (6 tendons total)	Three bundles of two mooring legs each. Tension legs are majority wire rope with short top and bottom chain sections for connection/installation, attached to gravity-suction anchors	TLP platform requires stiff high-tension mooring lines, as provided by wire rope. Suction-gravity anchors are suited for TLP because weight provides steady vertical capacity and suction can provide strong capacity against dynamic loads.
DemoSATH	Single-point turret mooring with 6 semi-taut rope-chain mooring lines	Single-point mooring from turret rigidly attached to platform, 6 semi-taut mooring lines with rope and chain, drag embedment anchors	Concrete platform is directional and designed to face into the waves, so a single-point mooring allows weathervaning and simplifies installation
New England Aqua Ventus I	3 lines considering catenary, semi-taut, and taut configurations	Catenary chain, semi-taut rope-chain, or taut rope configuration (with minimal if any chain at seabed), drag embedment anchors	Three options offer trade-offs between minimizing seabed impact and logistical simplicity

WP2: 電力ケーブルの配置



WP2: ダイナミックケーブルの種類

	Configuration Type	Ancillaries	General Comments
	Catenary (freely hanging)	Bend stiffener (at hang-off), cable protection at touchdown point (TDP)	Does not decouple the motions of the FOWT from the TDP (critical for damage) Use in deep water would require distributed buoyancy to avoid excessive tensions due to weight
	Lazy wave	Buoyancy modules, bend stiffeners, cable protection (at TDP)	A common configuration; currents could cause excess TDP motion (critical for damage)
	Tethered wave (reverse pliant wave)	Tether, clamp, buoyancy modules, bend stiffeners, hold-down/hold-back anchors	A common configuration; the tether limits TDP motion, making it more suitable for areas where currents or shallow water would otherwise lead to large TDP motion

	Steep-wave	Buoyancy modules, subsea base, bend stiffeners	Cable vertically connected to a subsea base through a bend stiffener; difficult to install
	Lazy S	Buoy with anchor and tether system, clamp, bend stiffener (at hang-off)	Like lazy wave but uses a tethered subsea buoy instead of buoyancy modules
	Chinese lantern	Buoyancy modules, bend stiffener, subsea base	Often used to connect hoses to oil and gas offloading buoys; not practical for power cables
	Suspended configuration	Buoyancy modules or subsea buoys, bend stiffeners	Used for offloading hoses in oil and gas applications; coupling analysis effects

WP2のまとめ

- WP内での議論の結果、WP2で対象とするアレイ(浮体式ウィンドファーム)の特性は、風車配置・係留システム・電力ケーブル配置とした。浮体と風車は既存のものを用いた。
- それぞれの特性について、既存のウィンドファーム、文献等の包括的なレビューを行った。
- ３種類の参照ウィンドファームについて、設計を実施中である。