ARE FLOATING PV SYSTEMS RELIABLE?

Sara Golroodbari

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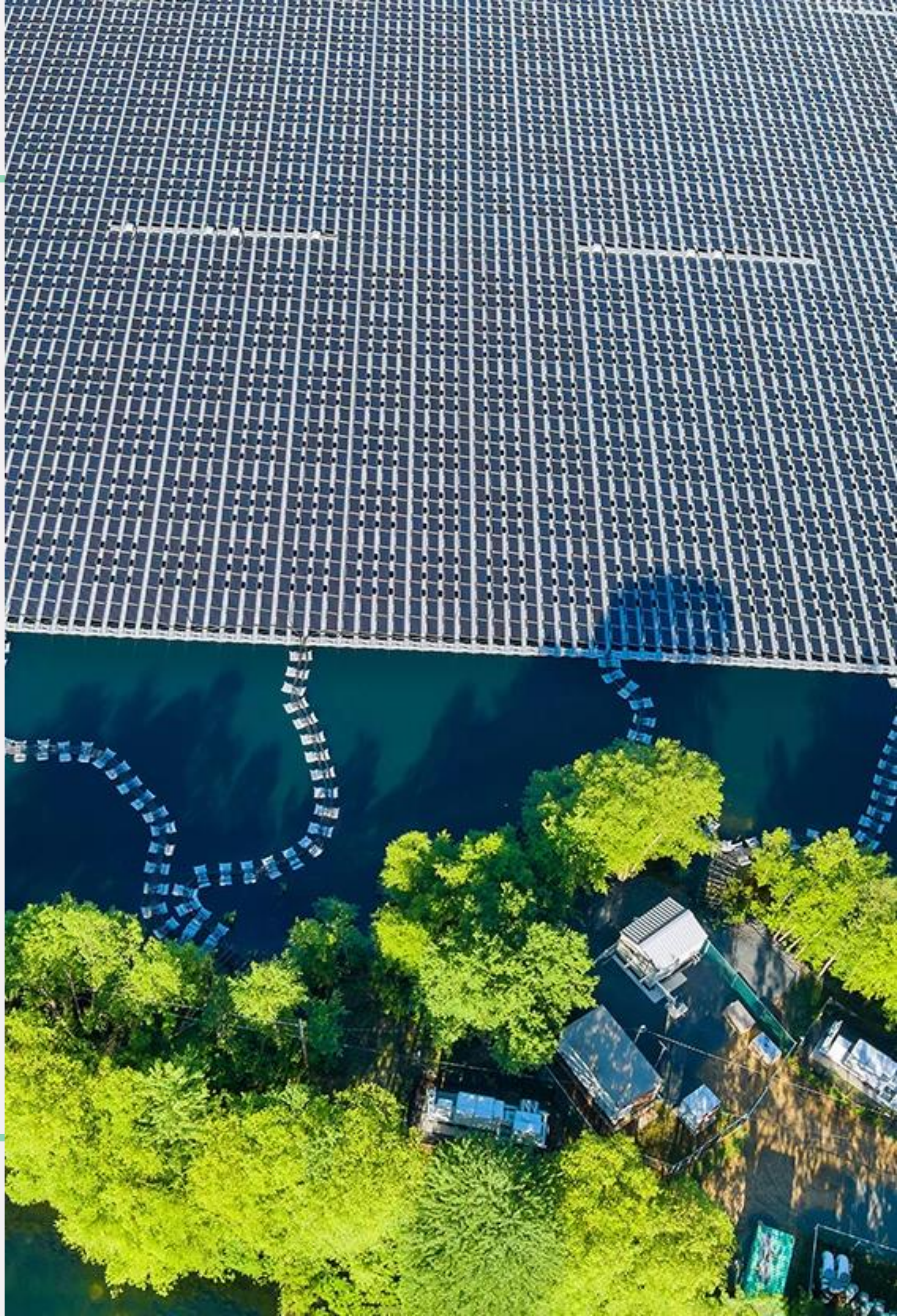
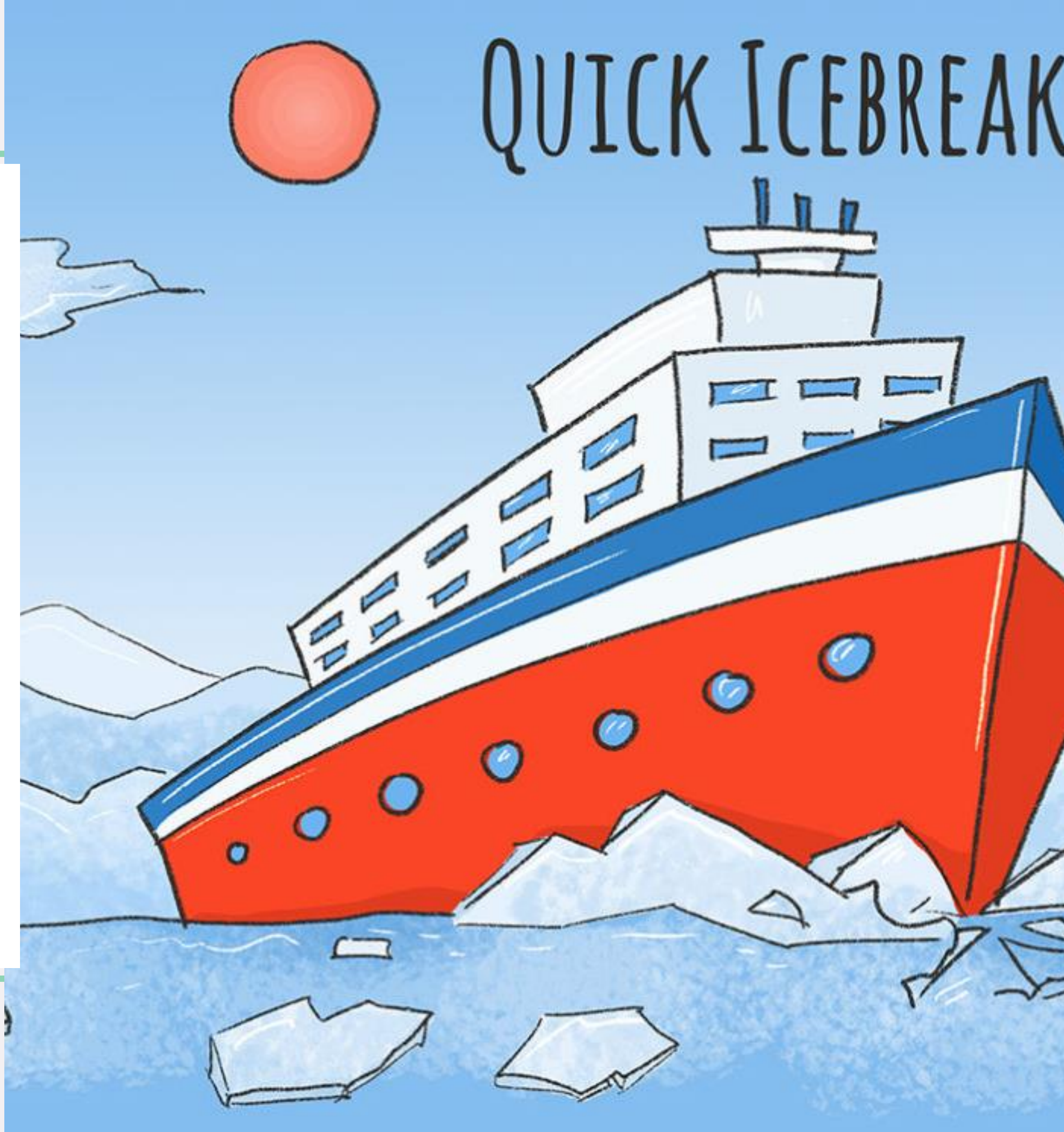


Icebreaker click!



Why Floating PV?

- Land-based PV systems might compete with other essential demands on land use, such as agriculture, nature reserves and recreation.
- Water cooling effect, which will increase the system efficiency.
- For small island nations, and for nations with comparatively large coastal areas, Offshore FPV could be considered in order to achieve the two aims of :
  - Reducing carbon emissions
  - Maintaining energy security

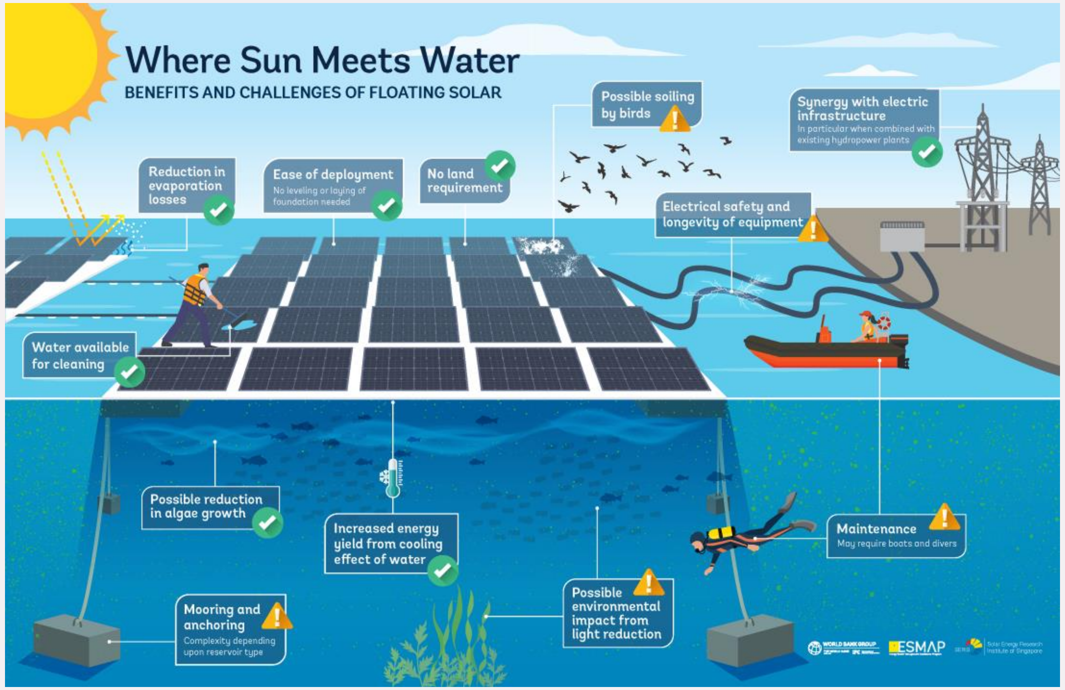
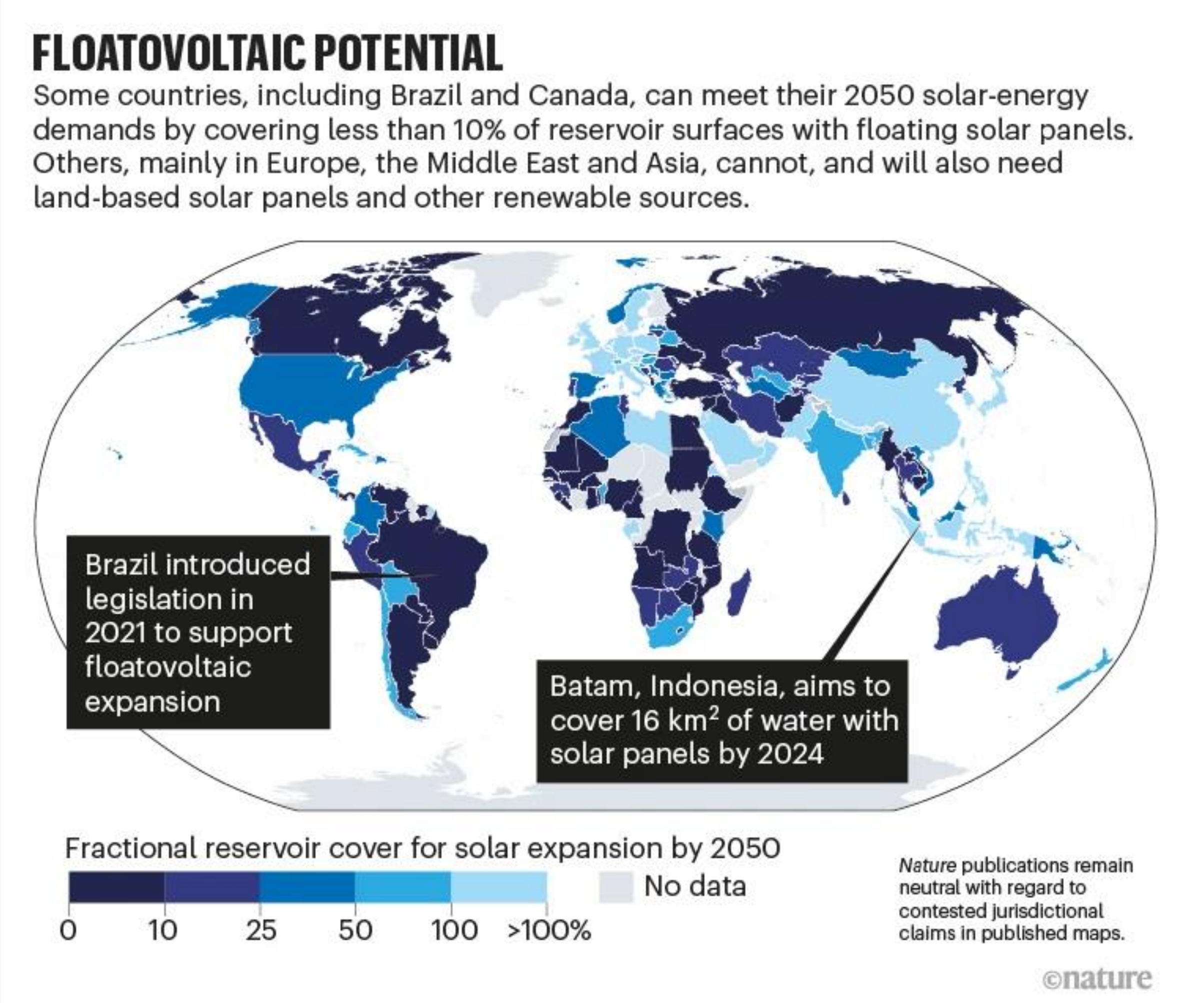


Figure credits goes to: World Bank Group

WHERE ARE WE ABOUT FPV SYSTEMS?

- As of 2020, the global installed capacity of floating solar panels was just 3 GW.
- Floatovoltaics are currently more expensive than land-based ones: 4–8% higher than that of ground-mounted solar power.
- The potential for expansion FPV is considerable, given the vast number of reservoirs worldwide — with a total area roughly equivalent to that of France.
- Globally, FPV is expected to grow by an average of 22% year-over-year through 2024, however, most of the projects are installed in Asia, followed by Europe.



Almeida, Rafael M., et al. "Floating solar power could help fight climate change—let's get it right." Nature 606.7913 (2022): 246-249.
Energy Sector Management Assistance Program, and Solar Energy Research Institute of Singapore. Where Sun Meets Water: Floating Solar Handbook for Practitioners. World Bank, 2019.
Molly Cox. The state of floating solar: Bigger projects, climbing capacity, new markets. Online: https://www. greentechmedia. com/articles/read/thestate-of-floating-solar-bigger-projects-andclimbingcapacity, 2019.

IS IT A RELIABLE SYSTEM?

FPV system Integration

- Floating PV system
  - Mechanical
    - Floater technology
    - Anchoring and Mooring
  - Electrical
    - Panels
    - Inverters
    - Cables and Connections
- Power system
  - Loss of load probability
  - Loss of expected energy
  - Expected demand not supplied
  - Loss of load frequency
- Environmental Impact
- Social impact

IS IT A RELIABLE SYSTEM?

FPV system Integration

Floating PV system

Mechanical

Electrical

Floater technology

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Panels

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Cables and Connections

Power system

Loss of load probability

Loss of expected energy

Expected demand not supplied

Loss of load frequency

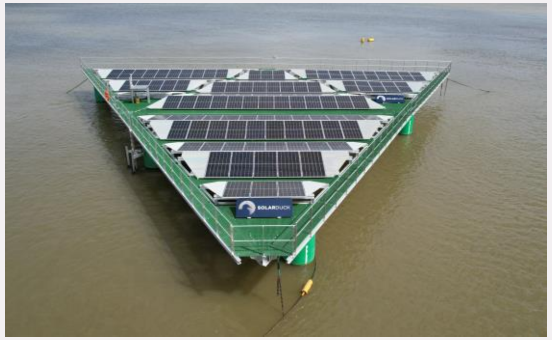
Environmental Impact

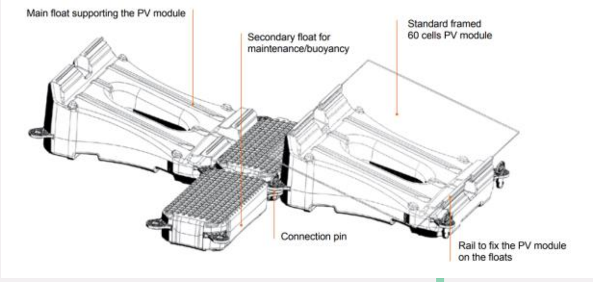
Social impact

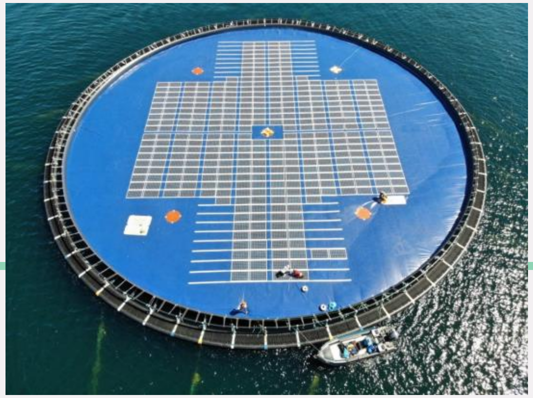
Performance

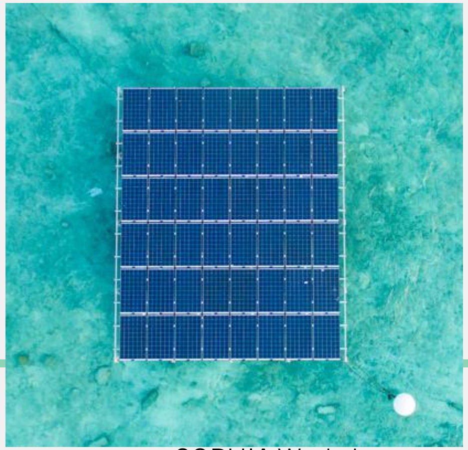
FLOATER TECHNOLOGY

- Floater technology
  - Pontoon-type
    - Pontoon concept
    - Raft concept
    - Truss Concept
  - Superficial type
    - Rigid
    - Flexible

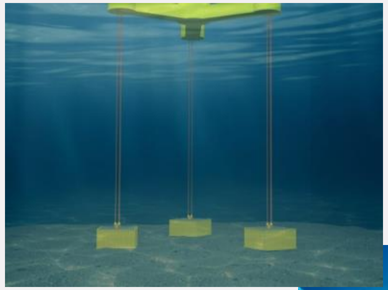


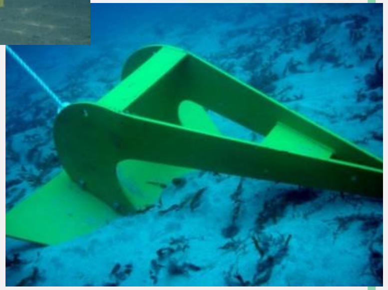




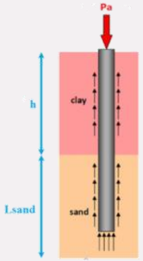


ANCHORING AND MOORING SYSTEM

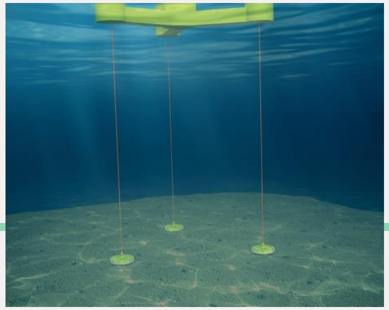




- Gravity Anchors: These are large concrete or steel blocks that are placed on the seabed or lakebed to provide weight and stability to the floating PV system.
- Drag Embedment Anchors: These are anchors that are designed to be dragged along the seabed or lakebed until they reach a point where they can hold the floating PV system in place.
- Pile Anchors: These are long steel or concrete poles that are driven into the seabed or lakebed to anchor the floating PV system in place.



- Suction Anchors: These are anchors that use a vacuum or suction to hold the floating PV system in place. They are typically used in areas where the seabed or lakebed is soft or sandy.



Claus, R., and M. López. "Key issues in the design of floating photovoltaic structures for the marine environment." Renewable and Sustainable Energy Reviews (2022): 112502.

MOORING CONCEPT

(a) Taut

(b) Taut spread

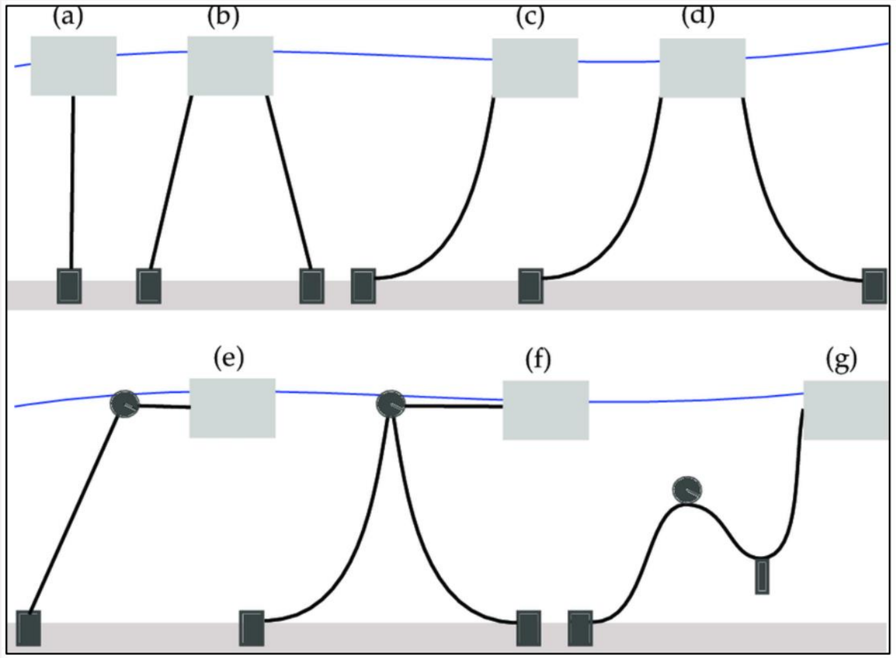
(c) Catenary

(d) Multi-catenary;

(e) Single anchor leg mooring (SALM);

(f) Catenary anchor leg mooring (CALM)

(g) Lazy-S.



Josh Davidson and John V Ringwood. Mathematical modelling of mooring systems for wave energy converters—a review. Energies, 10(5):666, 2017.

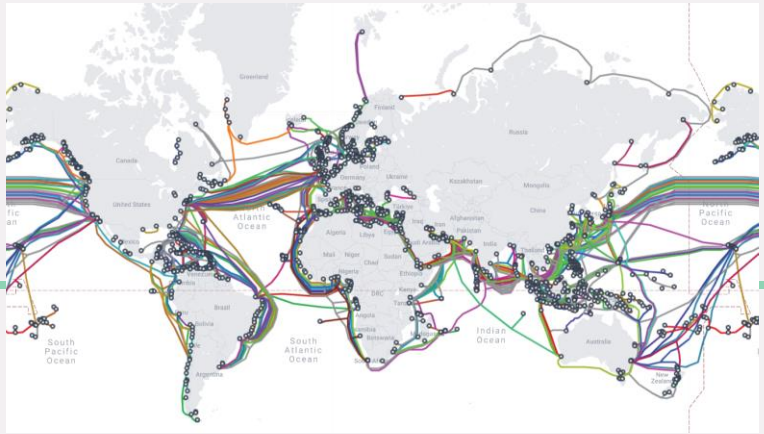
ELECTRICAL COMPONENTS

- Panel , higher degradation rate due to humidity, soiling, and biofouling
- Inverter, High IP and anti corrosion level inverters are required
  - Example: the SG3400HV PV inverter solution which reaches a level C5 of anti-corrosion. Coming together with the combining box of protection level IP67, the solution proves resilient in the harsh reservoir conditions.
- Cable and connection : On water and under water.

  Due to humidity, mechanical stress, pressure, UV extra

  Strong cables are needed.

Thailand’s Largest Floating PV Plant, 58.5 MW project in Sungrow supplied



Submarine Cable Map

ENVIRONMENTAL IMPACTS

- Environmental impacts could be from the effect of the following variables:
- Change in the penetrating light due to the FPV deployment
- Water body temperature difference due to operation of the floating modules
- The oxygen content of the water
- Fish aggregation
- Biofouling
- Changes in macrobenthos
- Habitat creation (e.g. for birds)

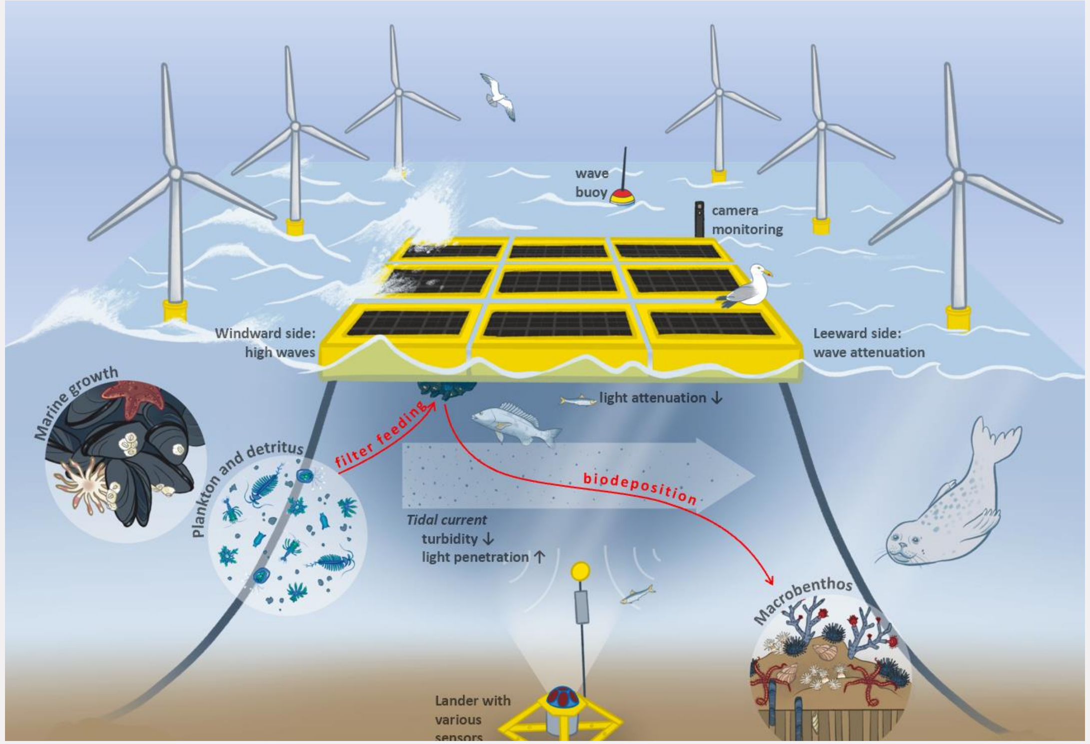
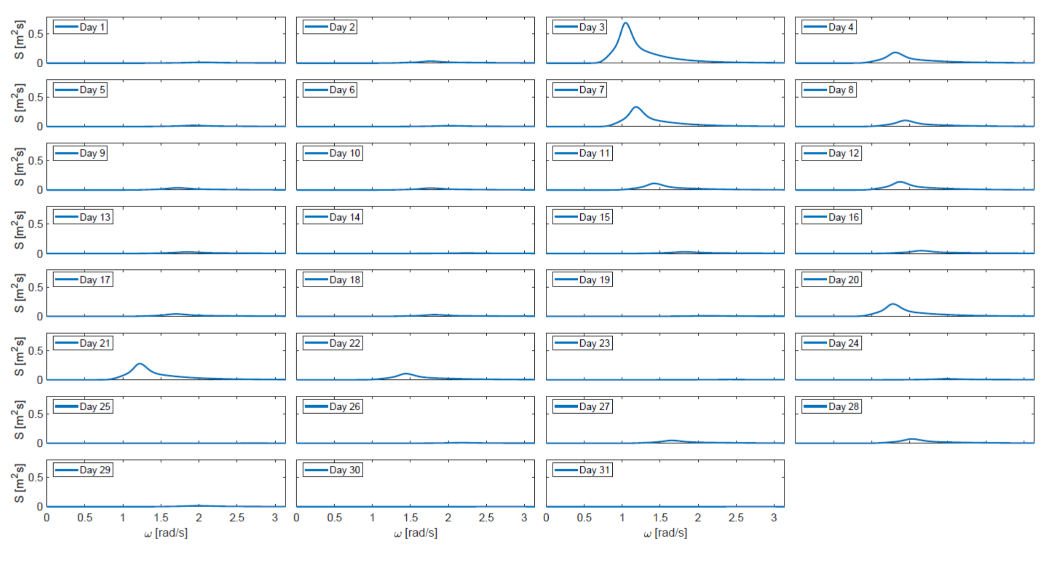


Figure credits goes to Oceans of Energy BV.

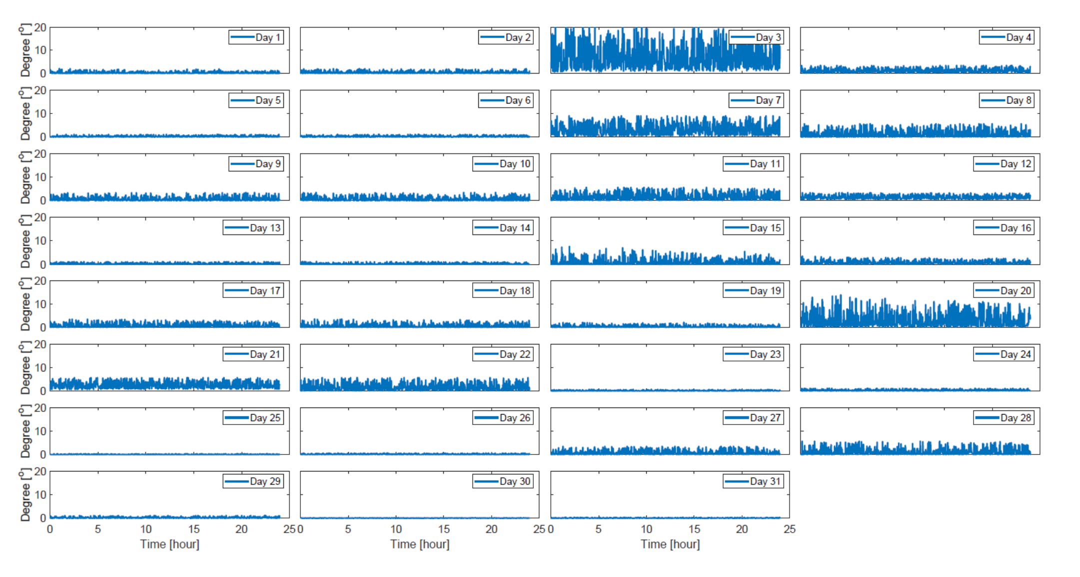
PERFORMANCE AND RELIABILITY

PERFORMANCE AND RELIABILITY

- Dynamic Irradiation
  - Dynamic Tilt and Orientation : based on the wind and wave effect we have dynamic tilt and orientation. Offshore floating systems could have large variations in the panel tilt.

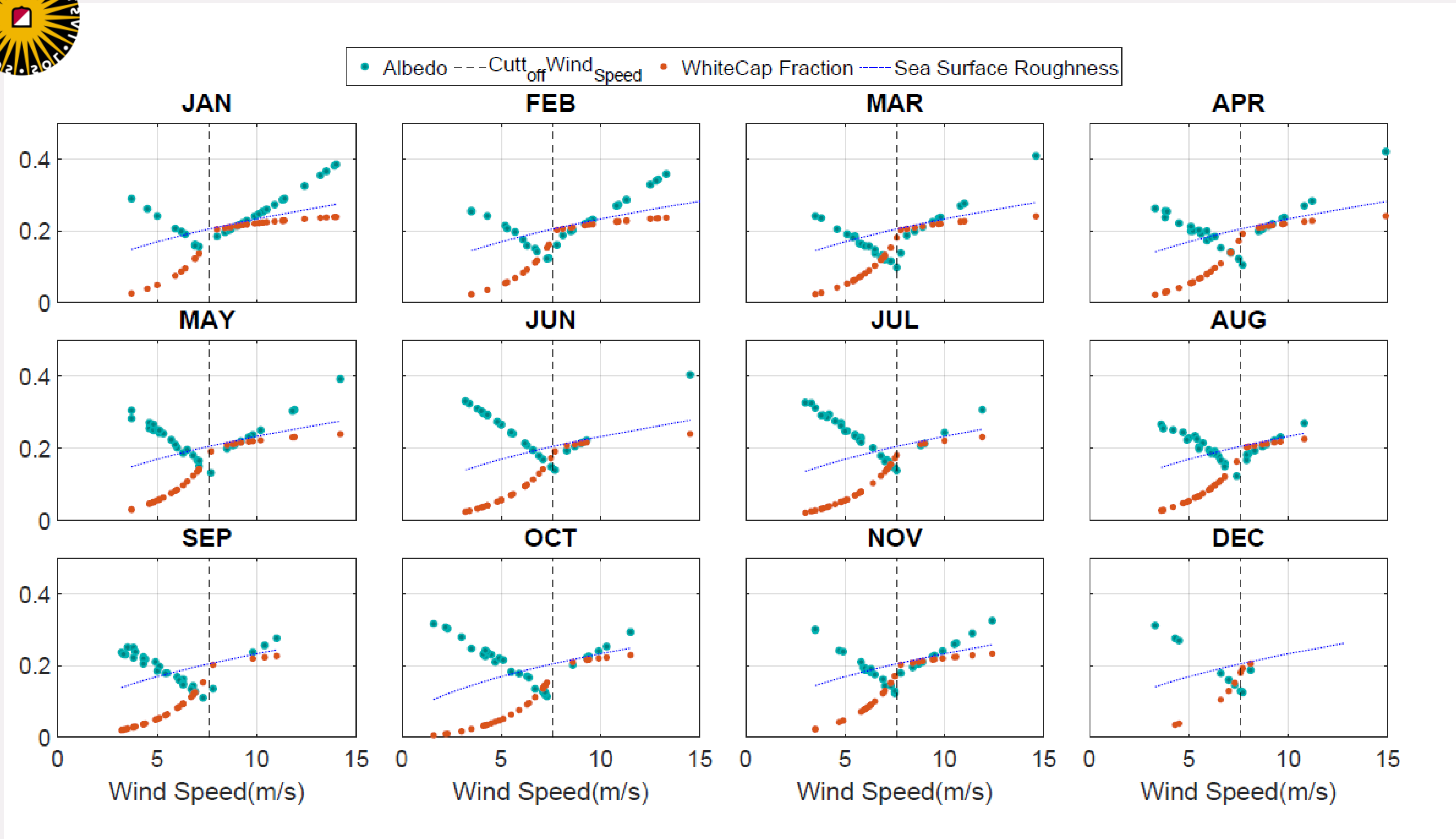


Joint North Sea Wave Project (JONSWAP) spectrum (JS) for all days of August 2016



The tilt angle of the pontoon for all days of August 2016

Sara Golroodbari and Wilfried van Sark. Simulation of performance differences between offshore and land-based photovoltaic systems. Progress in Photovoltaics: Research and Applications, 2020.



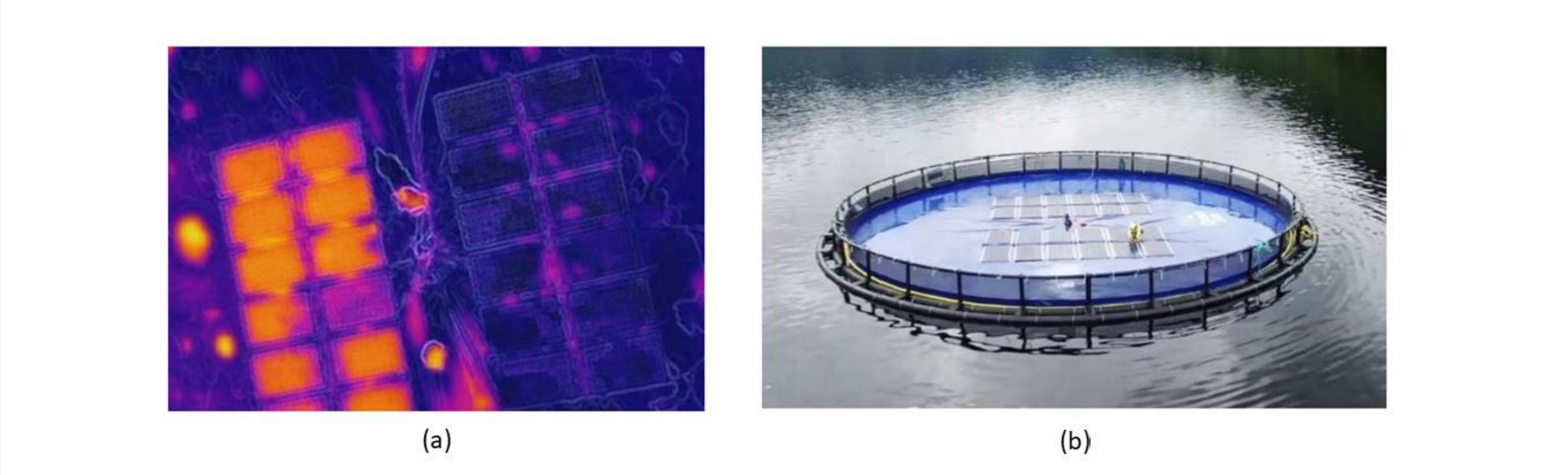
amic tilt and
ilt.

ation of white caps
solar zenith angles.

Scatter plots of albedo and whitecap fraction as a function of wind speed for the year 2016.

Sara Golroodbari and Wilfried van Sark. On the effect of dynamic albedo on performance modelling of offshore floating photovoltaic systems. Solar Energy Advances, 2:100016, 2022.

PERFORMANCE AND RELIABILITY



- sea
- r, or
nge

(a) IR image from the installation at Skafta. The difference in temperature between water-cooled (right) and air-cooled (left) is clearly visible, (b) Ocean Sun's pilot located at the west coast of Norway

J H Seij, I H Lereng, P De Paoli, M B Ogaard, G Otnes, S Bragstad, B Bjorneklett, and E Marstein. The performance of a floating pv plant at the west coast of norway. In Proceedings of 36th European Photovoltaic Solar Energy Conference (EUPVSEC), pages 1763–1767, Marseille, France, 2019.

PERFORMANCE AND RELIABILITY

- Dynamic Irradiation
  - Dynamic Tilt and Orientation : based on the wind and wave effect we have dynamic tilt and orientation. Offshore floating systems could have large variations in the panel tilt.
  - Dynamic Albedo: One important factor in dynamic albedo variation is the formation of white caps on the sea surface which are more clearly effective during months with larger solar zenith angles.
- Operating temperature :For FPV technologies where the modules are in direct contact with water, or only separated from the waterbody by a highly heat conductive material, the dominating heat exchange mechanism will be conduction.
- Mismatch: for systems where all panels on one floater are connected in one string mismatch is much lower.
- Soiling and shading: For FPV systems, the risk near shading is reduced, and so is generally soiling loss due to dirt and sand. However, soiling loss due to bird droppings can be prominent.

SOME EXAMPLES

- Land-based and offshore floating comparison in the Netherlands
- Offshore floating Comparison between the North Sea and Mediterranean
- Offshore floating world-wide

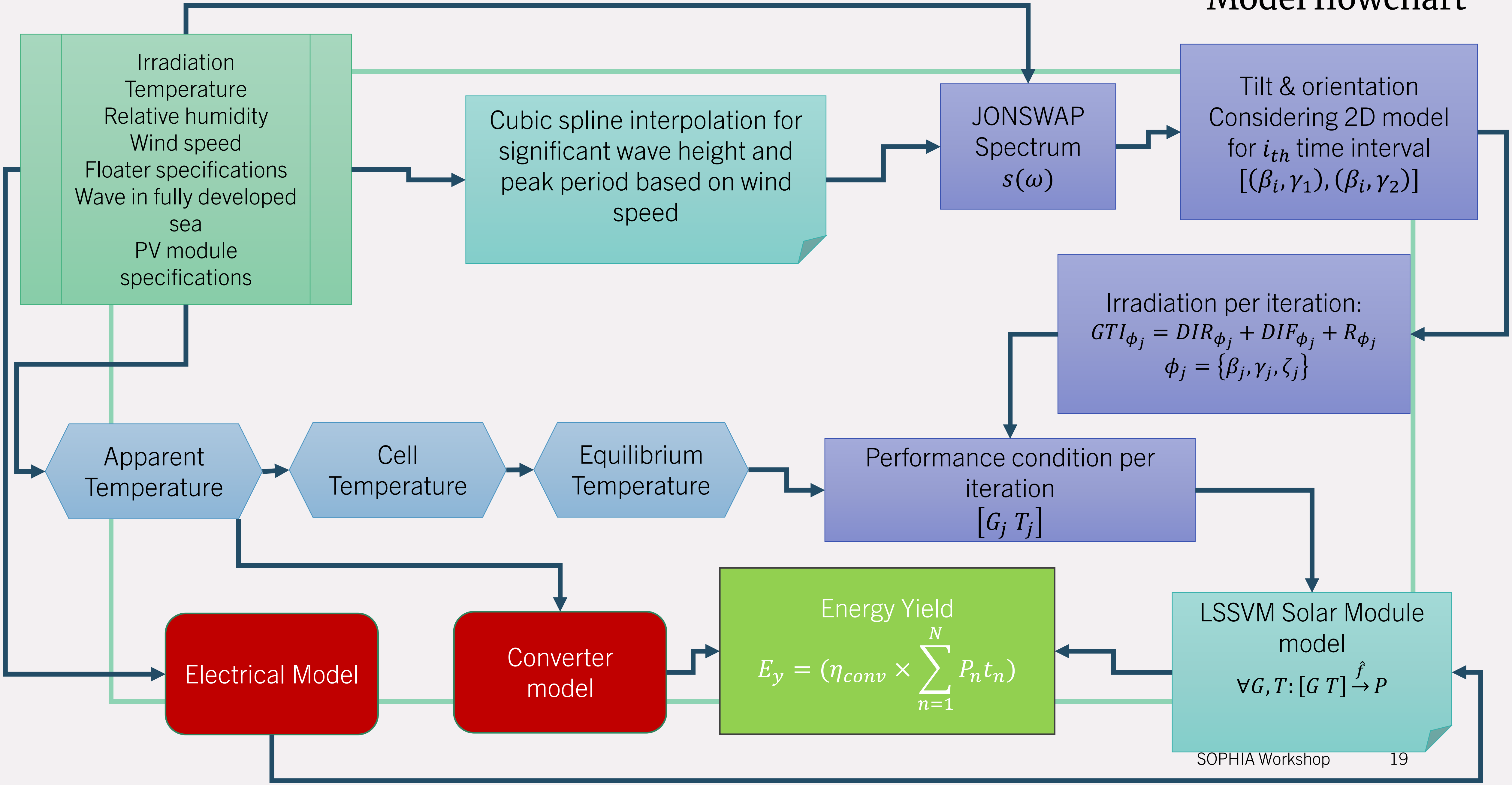
FPV

- Ambient temperature
- Irradiation (GHI, DIF, DIR, R)
- Tilt angle (dynamic, initial value = 0)
- Orientation (dynamic)
- Albedo (dynamic)

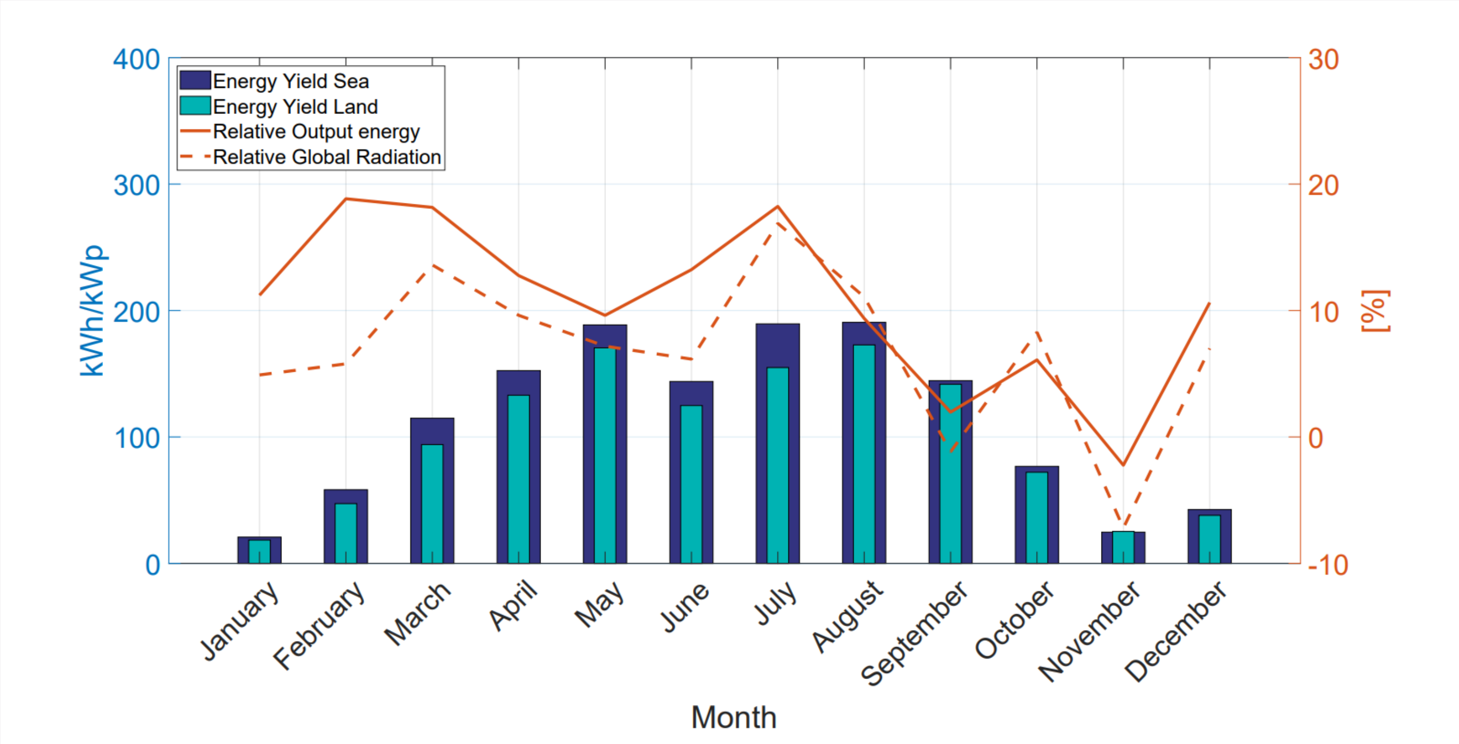
LBPV

- Ambient temperature
- Irradiation (GHI, DIF, DIR, R)
- Tilt angle (3 degree)
- Orientation (south-east)
- Albedo

Model flowchart

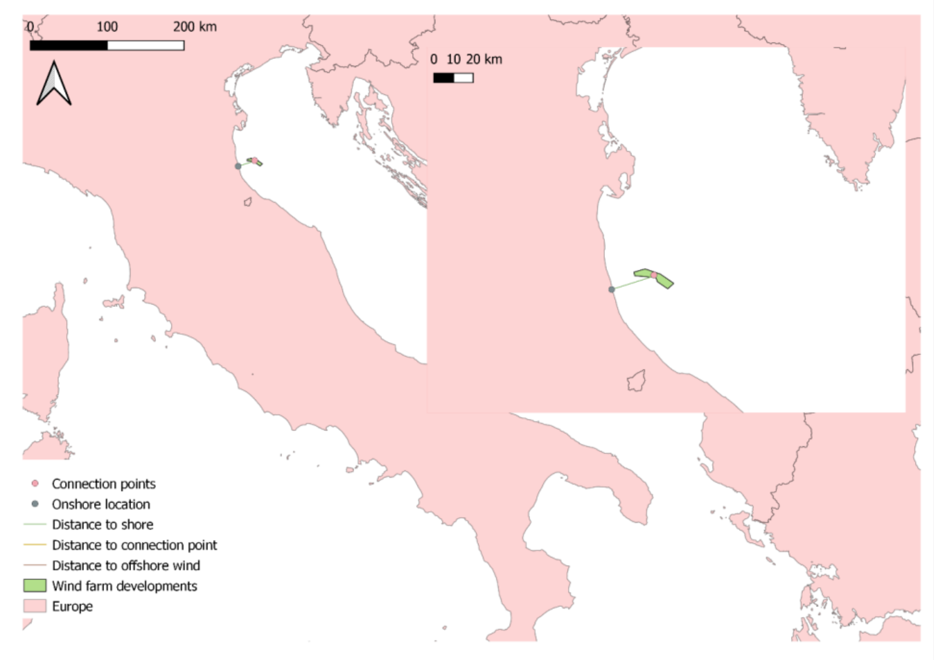


PERFORMANCE DIFFERENCES

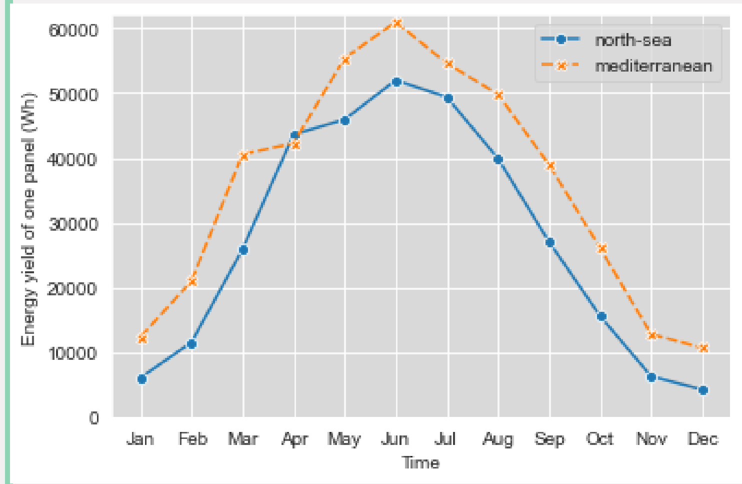


Left axis, normalized energy yield from two different systems. Right axis, relative output difference from two systems

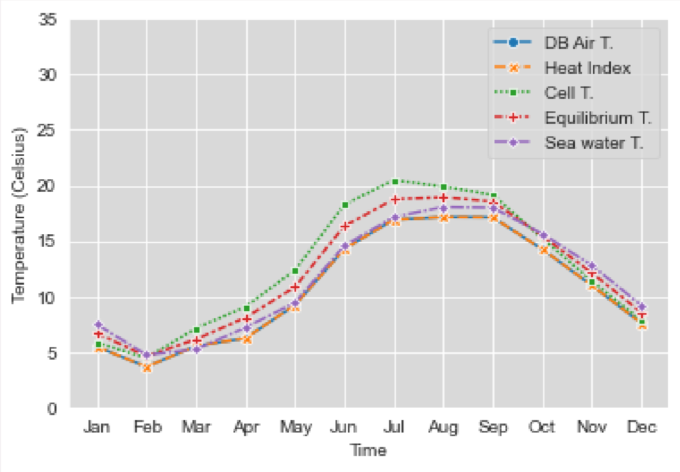
COMPARISON BETWEEN NORTH SEA AND MEDITERRANEAN



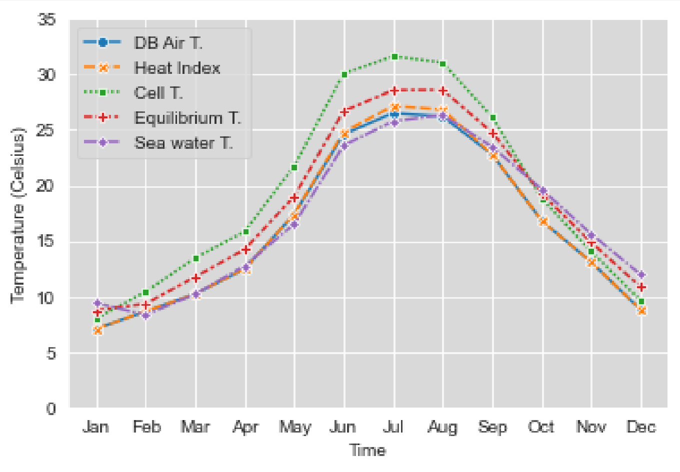
OUTPUTS FROM 100 MWP OFFSHORE SOLAR FARM AT BOTH LOCATIONS



Annual AC-output of the offshore FPV system case studies.



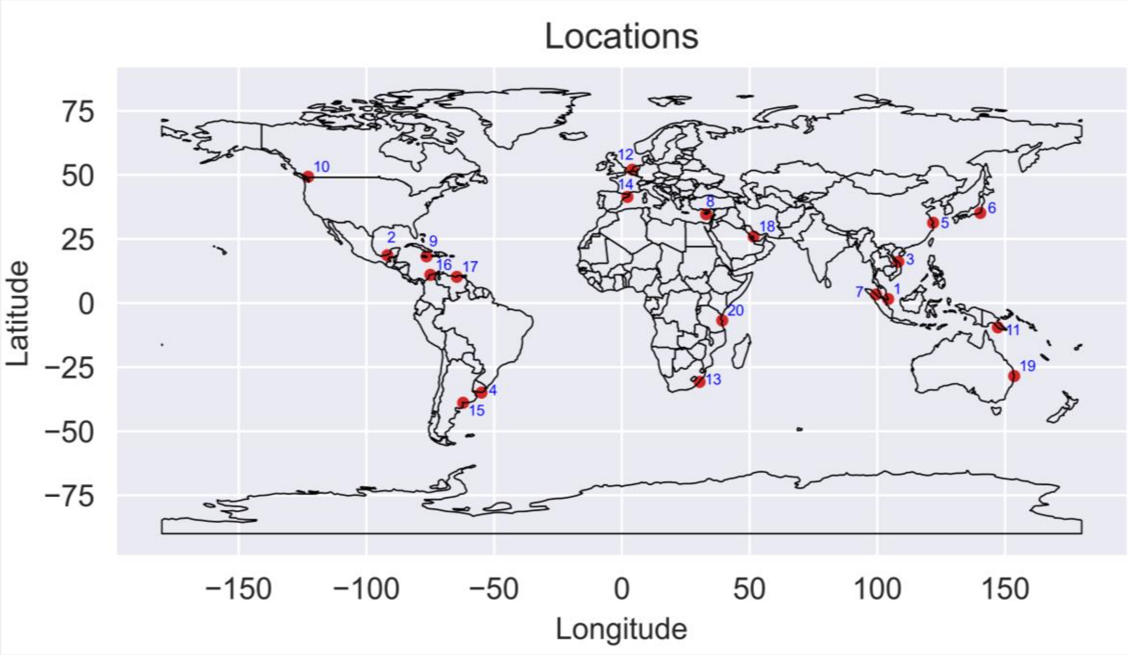
The different temperatures considered for the calculation of the operating cell temperature (North-Sea).

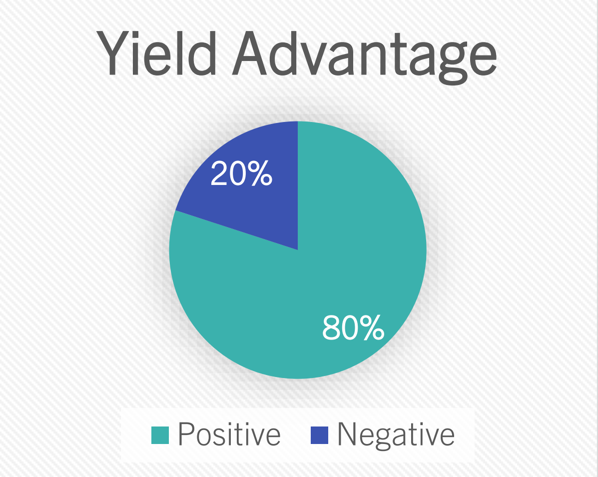


The different temperatures considered for the calculation of the operating cell temperature (Mediterranean).

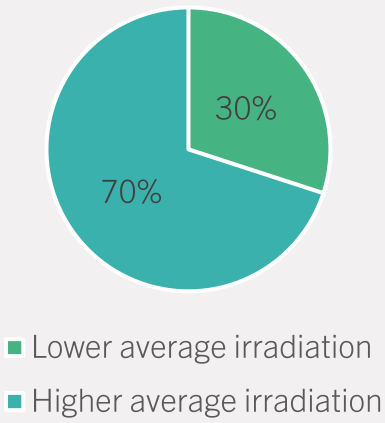
No.	Name	Country	latitude	longitude
	Code	(degrees)	(degrees)	Current
1	Bandar Penawar	MYS	1.56N	104.23E
2	Ciudad del Carmen	MEX	18.65N	91.81W
3	DaNang Port	VNM	16.08N	108.22E
4	El Emir	URY	34.96S	54.94W
5	Hengsha Island	CHN	31.32N	121.85E
6	Katsuura	JPN	35.16N	140.32E
7	Kwala Tanjung	IDN	3.35N	99.45E
8	Limassol Port	CYP	34.65N	33.016E
9	Port Antonio	JAM	18.18N	76.45W
10	Port Renfrew	CAN	48.55N	124.43W
11	Port Moresby	PNG	9.47S	147.16E
12	Port of Rotterdam	NLD	51.98N	4.13E
13	Port Shepstone	ZAF	30.73S	30.45E
14	Port Vell	ESP	41.38N	2.18E
15	Puerto Belgrano	ARG	38.89S	62.10W
16	Puerto Colombia	COL	10.99N	74.96W
17	Puerto La Cruz	VEN	10.21N	64.63W
18	Ras Laffan	QAT	25.92N	51.58E
19	South Golden Beach	AUS	28.50S	153.55E
20	Tanzania Port	TZA	6.82S	39.29E

WORLDWIDE COMPARISON





Irradiation level for OFPV compared to LBPV



No.	Site	Yield		Offshore	Relative
		Offshore	Inland	advantage	offshore advantage
	(kWh/kWp)	(kWh/kWp)	(kWh/kWp)	(%)	
1	Bandar Penawar	1658.65	1514.35	144.30	9.53
2	Ciudad del Carmen	1899.62	1677.71	221.90	13.22
3	DaNang Port	1589.96	1328.50	261.45	19.68
4	El Emir	1639.97	1549.98	89.99	5.80
5	Hengsha Island	1259.64	1263.69	-4.05	-0.32
6	Katsuura	1304.28	1321.14	-16.86	-1.27
7	Kwala Tanjung	1472.17	1484.61	-12.44	-0.83
8	New Limassol Port	1818.66	1654.61	164.05	9.91
9	Port Antonio	1750.85	1699.01	51.84	3.05
10	Port Coquitlam	1255.03	1115.08	139.95	12.91
11	Port Moresby	1711.61	1469.96	241.64	16.43
12	Port of Rotterdam	1117.90	1037.93	79.97	7.70
13	Port Shepstone	1584.99	1646.81	-61.81	-3.84
14	Port Vell	1550.65	1521.49	29.15	1.91
15	Puerto Belgrano	1681.68	1632.73	48.94	2.99
16	Puerto Colombia	1932.02	1700.09	231.91	13.64
17	Puerto La Cruz	1943.69	1727.55	216.13	12.51
18	Ras Laffan	1811.22	1677.09	134.13	7.99
19	South Golden Beach	1752.98	1668.95	84.03	5.03
20	Tanzania Port	1889.43	1653.09	236.33	14.29

QUESTIONS AND EVALUATION