Offshore Floating PV
DC and AC Yield Analysis Considering Wave Effects

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PVPMC, Mendrisio, Switzerland

TU Delft

Offshore Floating PV (OFPV)

Benefits

- No land occupancy
- Heat sink effect of water
- Reduced water evaporation

Challenges

- Durability
- Increased costs
- **Effect of waves**

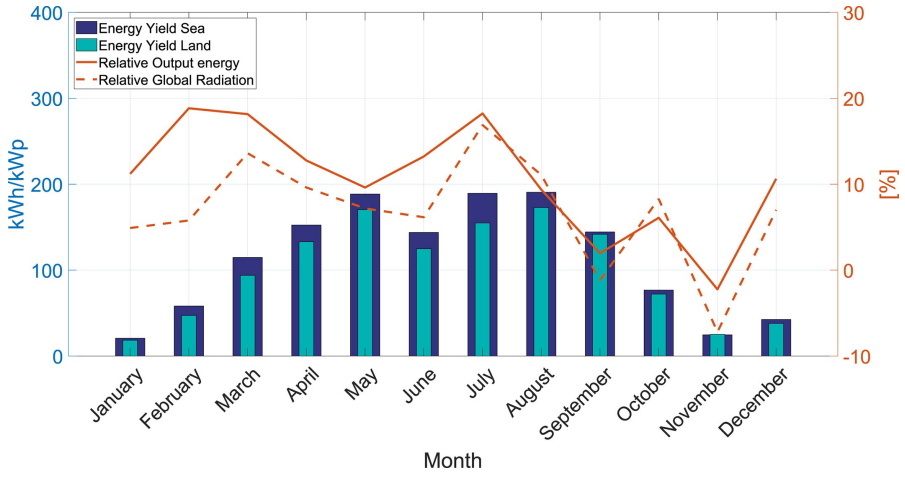
[1]

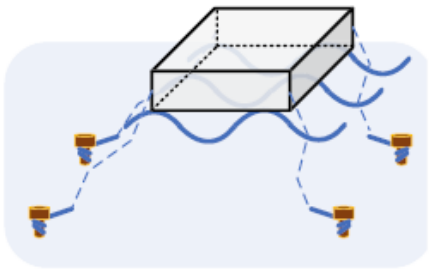
H. Ziar, *10 breakthrough ideas in energy for the next 10 years*, 30-43 (2021)
[1] H. Liu et al, *Prog Photovolt*, **26**.12: 957-967 (2018)

Previous Work[1]

- **Compare performance of a PV system on land and at sea**
  - Effect of sea waves, wind speed and relative humidity
  - Annual DC energy yield of OFPV was 13% higher than horizontal land-based

- Only one axis of rotation considered
- Effect of waves on inverter efficiency should be addressed



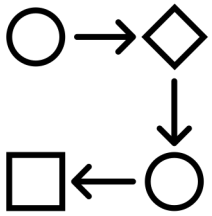


[1] S. Z. Golroodbari & W. van Sark, *Prog Photovolt* **28**:873–886 (2020)

Objective

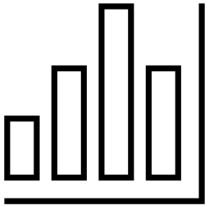
Study the waves effect on DC & AC yield
of an OFPV system considering two axes of rotation

Model Overview

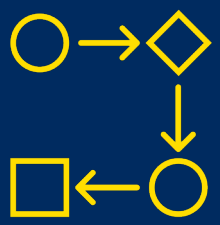


Inputs

Results



Model Overview



Inputs

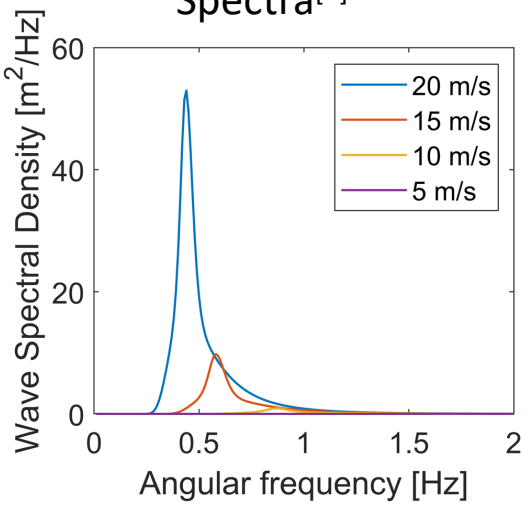
Results

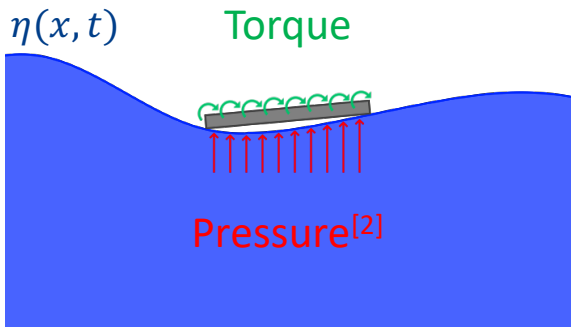
Methodology

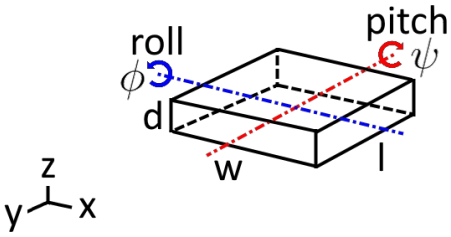
Weather conditions

ed decomposition

JONSWAP Spectra[1]

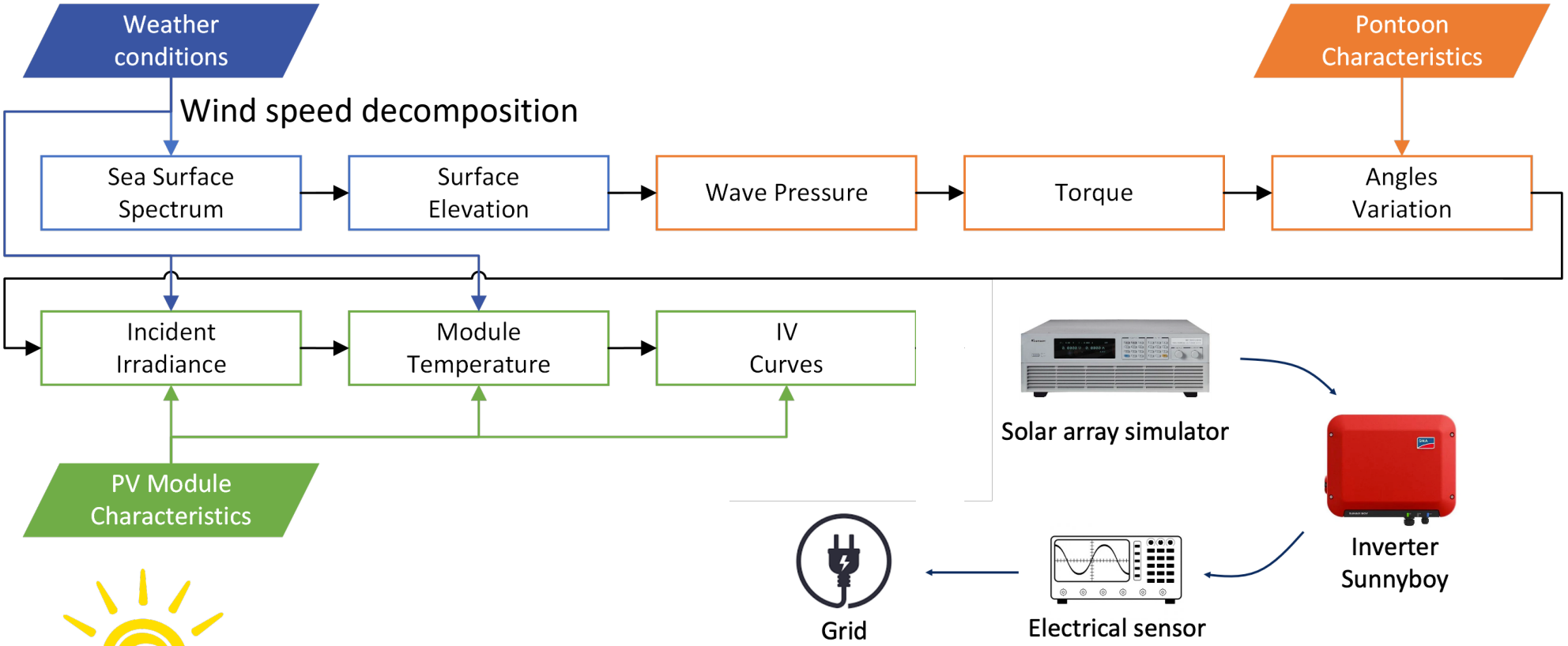






[1] K. Hasselmann et al. *Ergaenzungsheft zur Deutschen Hydrographischen Zeitschrift*, Reihe A (1973)
[2] J. Mani, "Coastal hydrodynamics", *PHI Learning Pvt. Ltd.* (2012)

Methodology

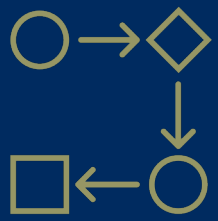


PVMD TOOLBOX[1]

Delft University of Technology

[1] M. R. Vogt et al. *Sol Energy Mater Sol Cells* **247**: 111944 (2022)

Model Overview



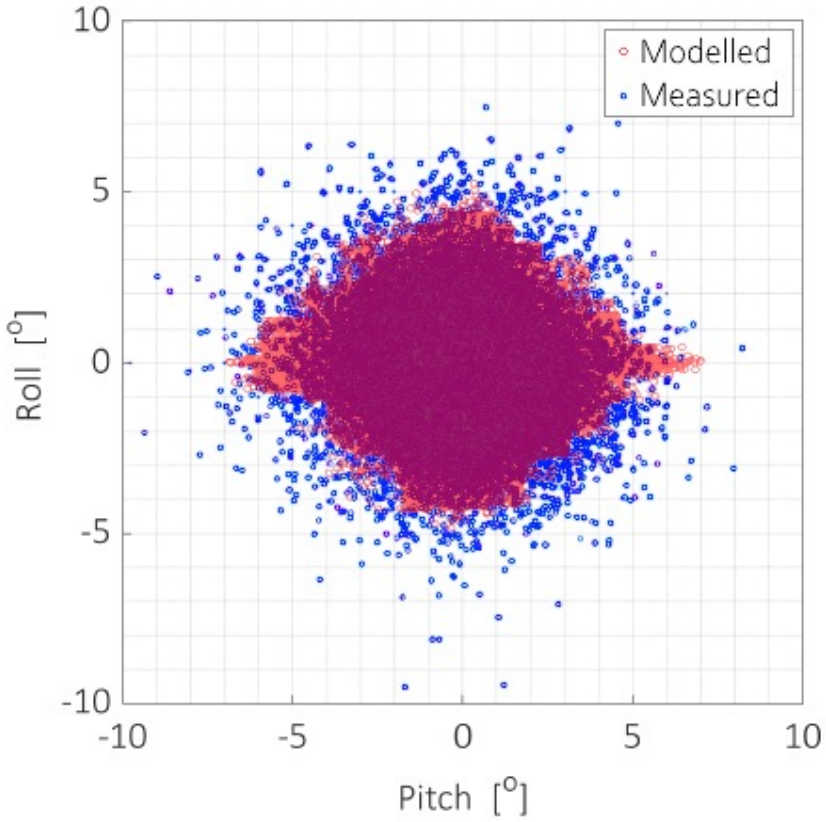
Inputs

Results

Validation

Pitch and roll measurements of OFPV system

Reasonable match



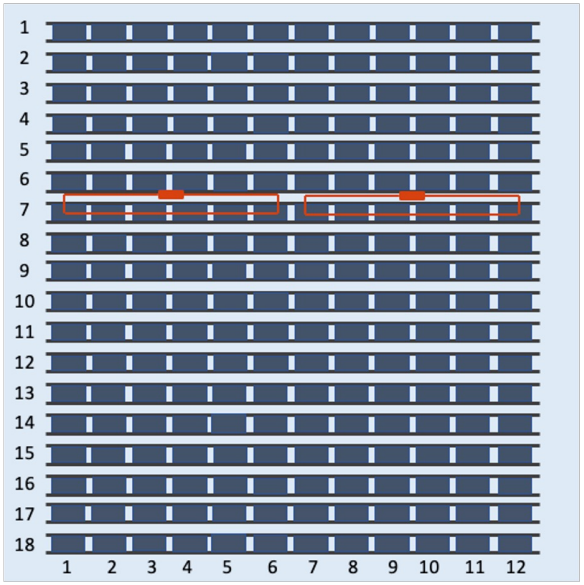
Thanks to the Oceans of Energy

Floating Body

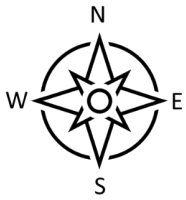
Considered a rigid body

Composed of floating cubes

[1]

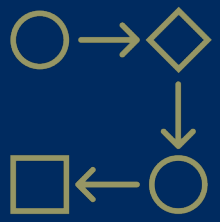


Pontoon dimensions
32 × 32 × 0.4 m^3
Modules in a column
18
Modules in a row
12
Number of modules
216



[1] ModernMarineGroup, “Floating Cubes: SunnyDock”

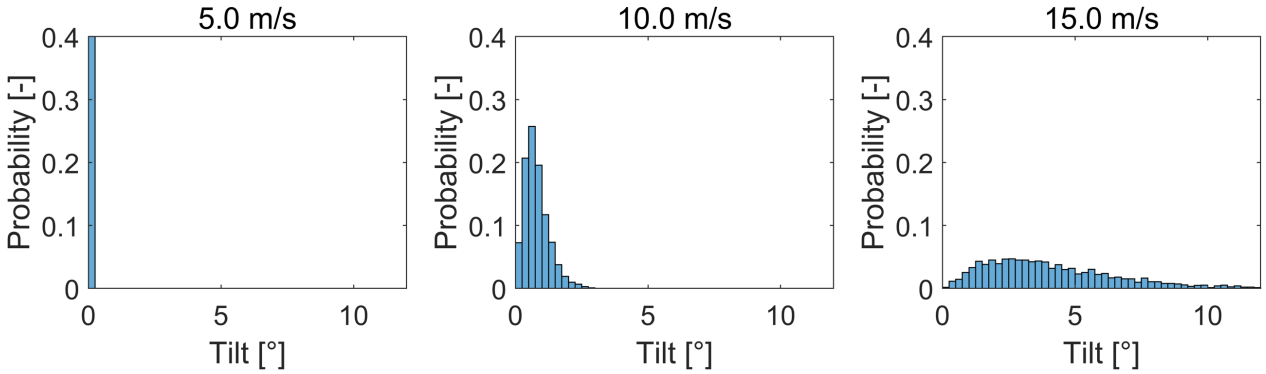
Model Overview



Inputs

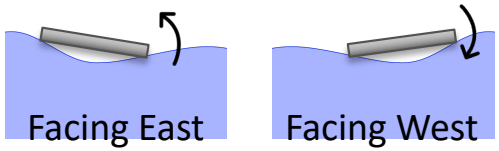
Results

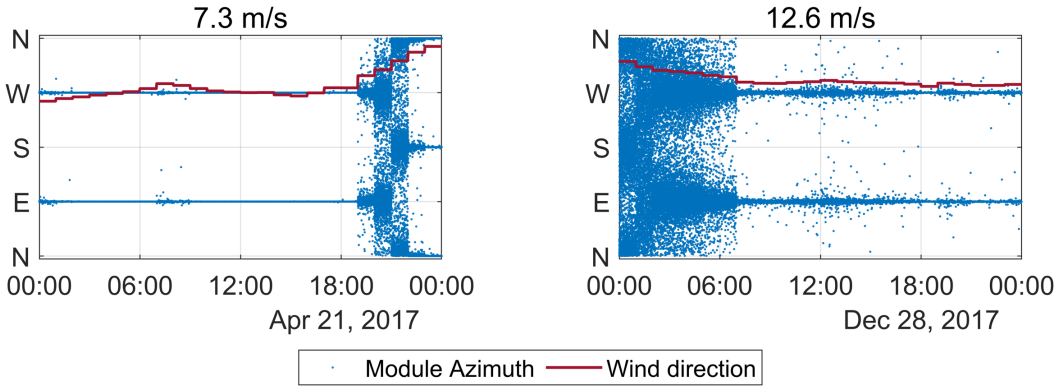
Tilt & Azimuth



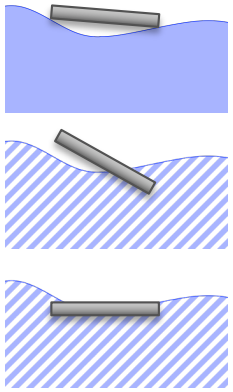
Stronger wind
→ higher tilt

Azimuth follows
wind direction





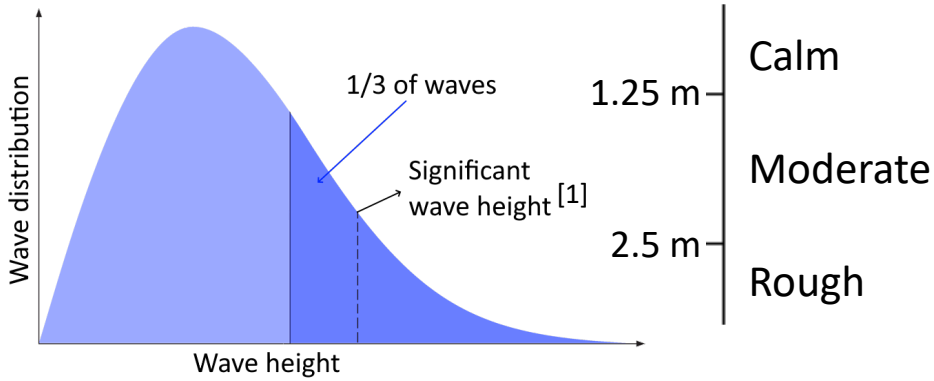
DC Yield

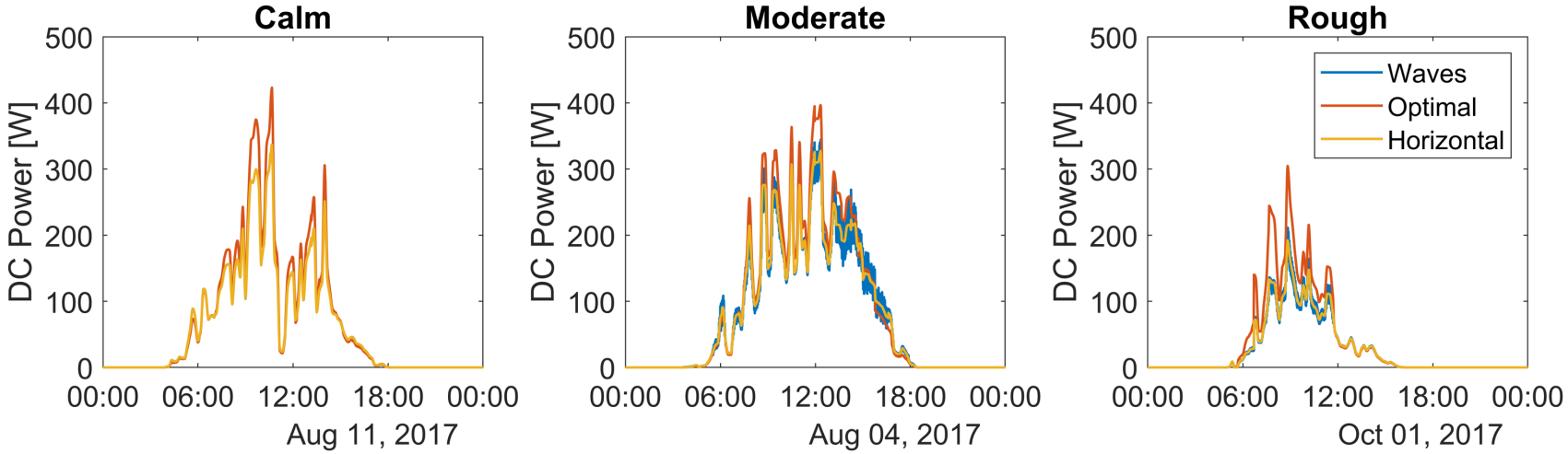


Waves

Optimal fix (34°)

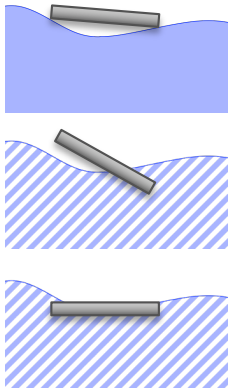
Horizontal fix (0°)





[1] J. Mani, "Coastal hydrodynamics", *PHI Learning Pvt. Ltd.* (2012)

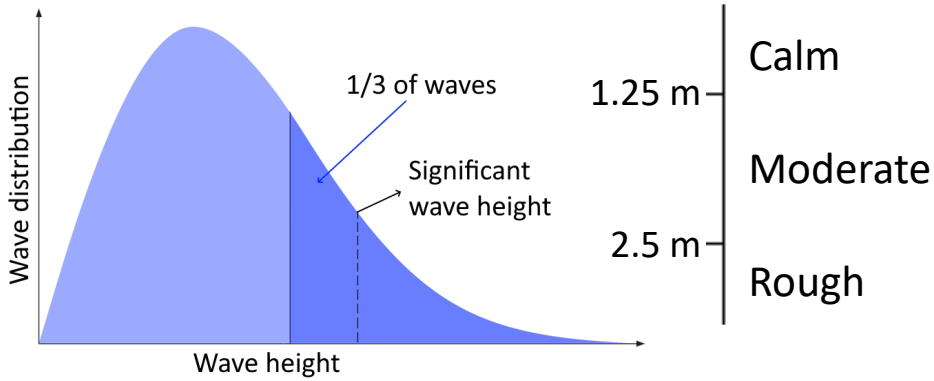
DC Yield

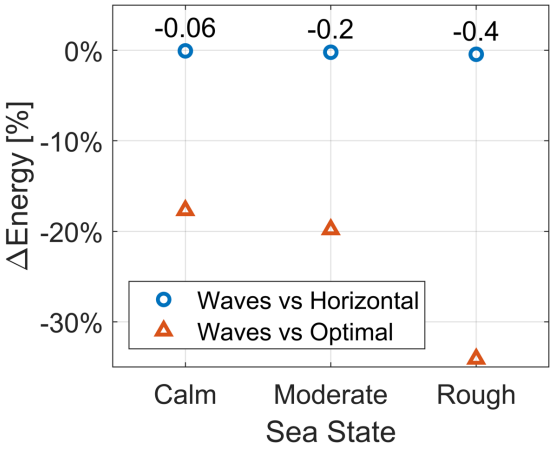


Waves

Optimal fix (34°)

Horizontal fix (0°)

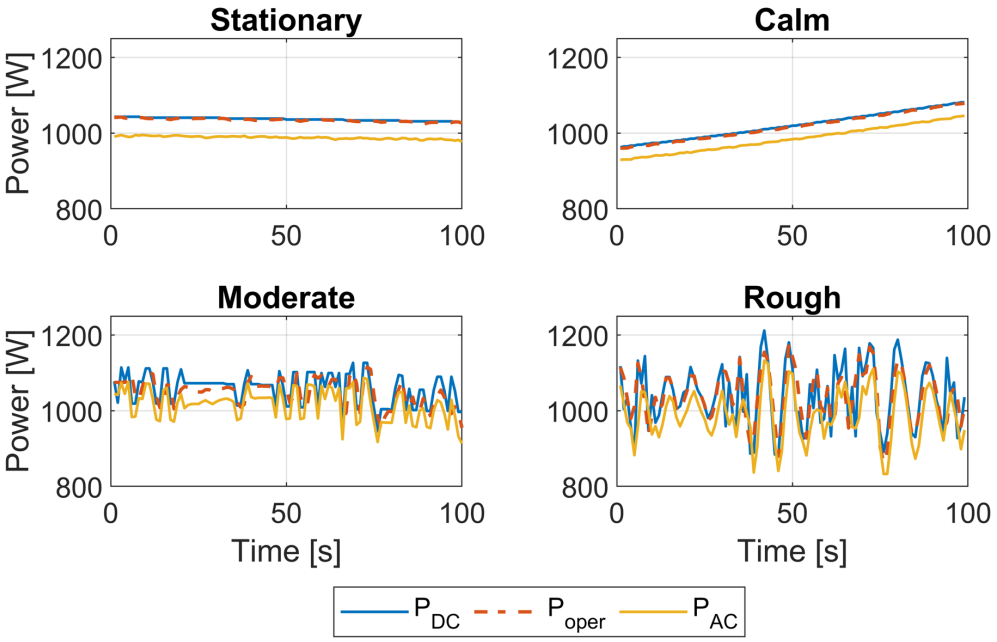




Negative yet negligible losses due to wave movement

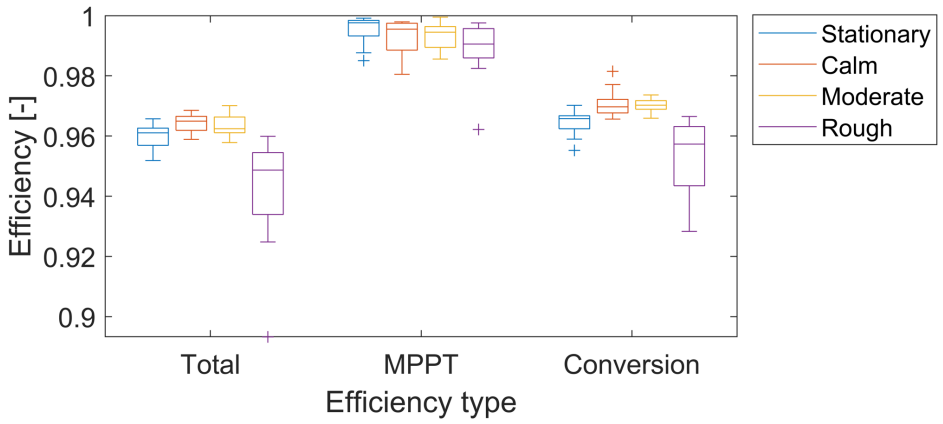
Annually, floating system produces 0.1% less than horizontal one and 14.6% less than optimal one

AC Yield Experiments



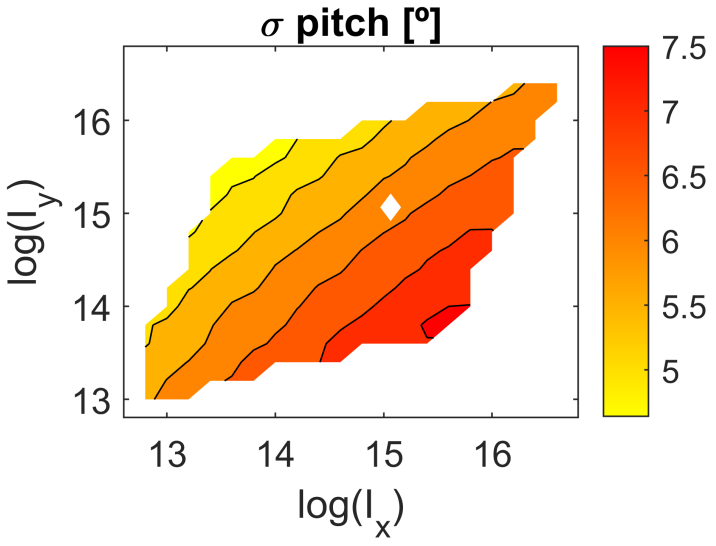
MPPT & conversion efficiency affected only during rough periods

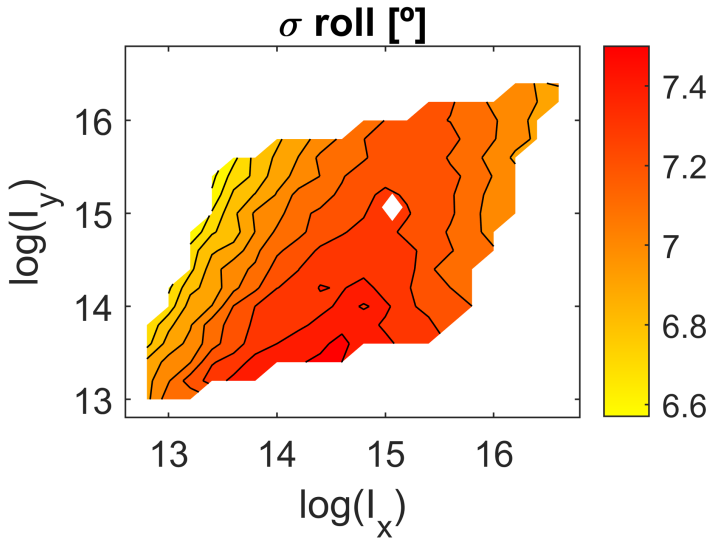
0.5% decrease in total efficiency



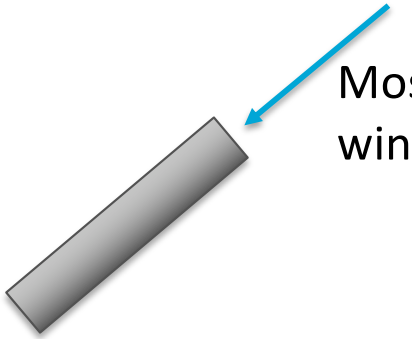
$$\eta_{tot} = \frac{P_{AC}}{P_{DC}} \qquad \eta_{MPPT} = \frac{P_{oper}}{P_{DC}} \qquad \eta_{con} = \frac{P_{AC}}{P_{oper}}$$

Should the Floater be Squared?





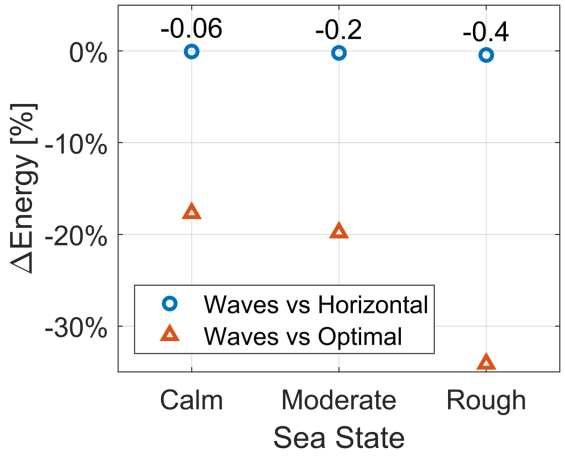
Heavy & wide floater aligned with wind reduces angle fluctuations

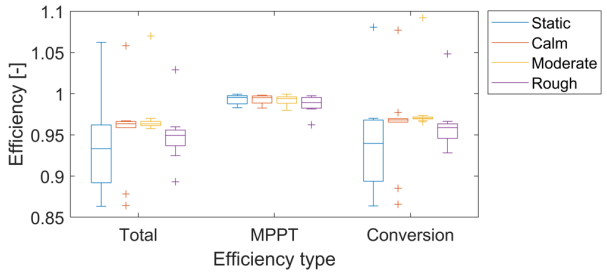


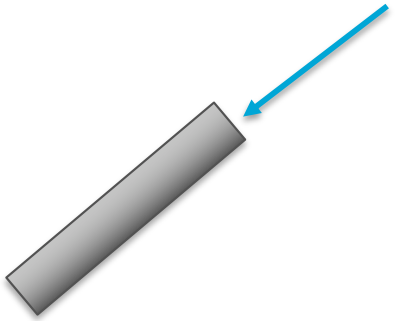
Most common wind direction

Conclusions

- Developed and validated a model including wave effects
- 0.5% higher production of floating system than horizontal one
- Waves only affect inverter efficiency 0.5% on rough days
- Wide floater aligned with main wind direction reduces fluctuations







A. Alcañiz et al., *Energy Convers. Manag, Under Review*

Thank you for your attention!

TU Delft Institutes

Urban Energy

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AgTech

Research funded by Trust-PV

TRUSTPV
PERFORMANCE RELIABILITY

PVMD funding

Rijksdienst voor Ondernemend Nederland

URBANEUROPE

HORIZON 2020

ERA-NET Cofund Partnership

Horizon Europe

NWO

HyET Solar
Flexible light weight solar modules

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Trust-PV website: **https://trust-pv.eu/**
PVMD web-lab: **www.tudelft.nl/dutchpvportal**
International PV Systems Summer School series: **www.tudelft.nl/pvsss**

Additional slides

Assumptions

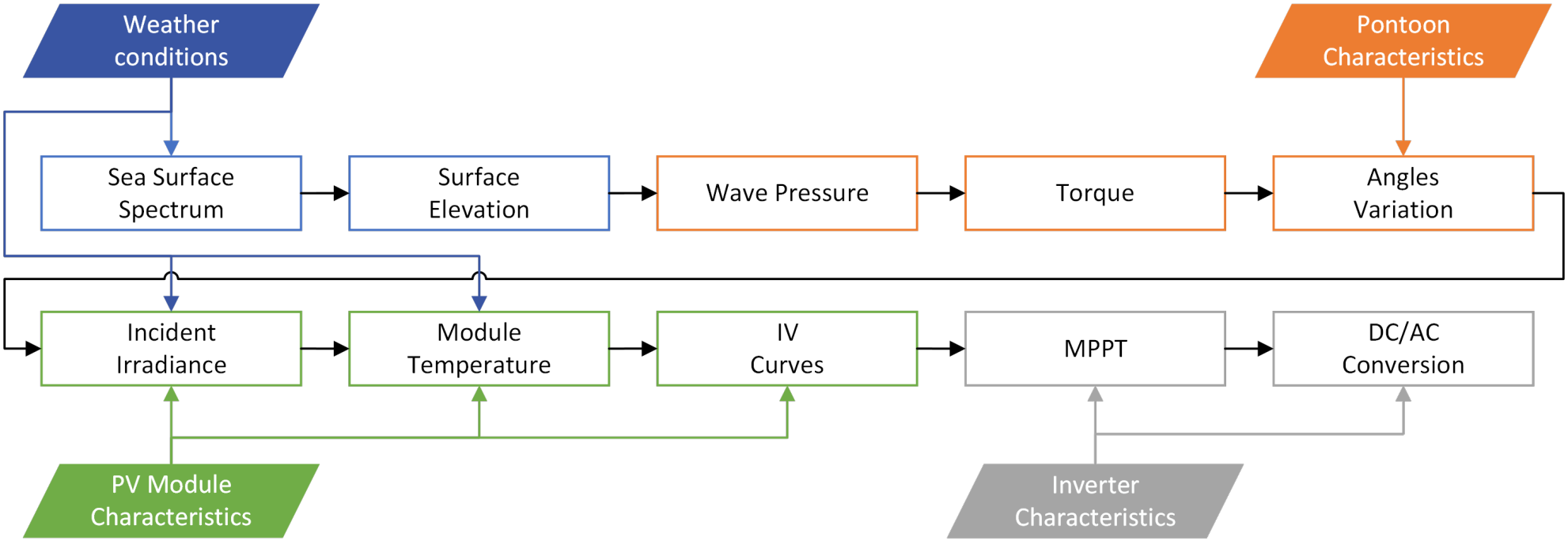
Waves model assumptions

- Floating body much smaller than the wavelength
- Coriolis force is ignored
- Viscosity is negligible
- Water is incompressible
- Deep water conditions

Mechanical assumptions

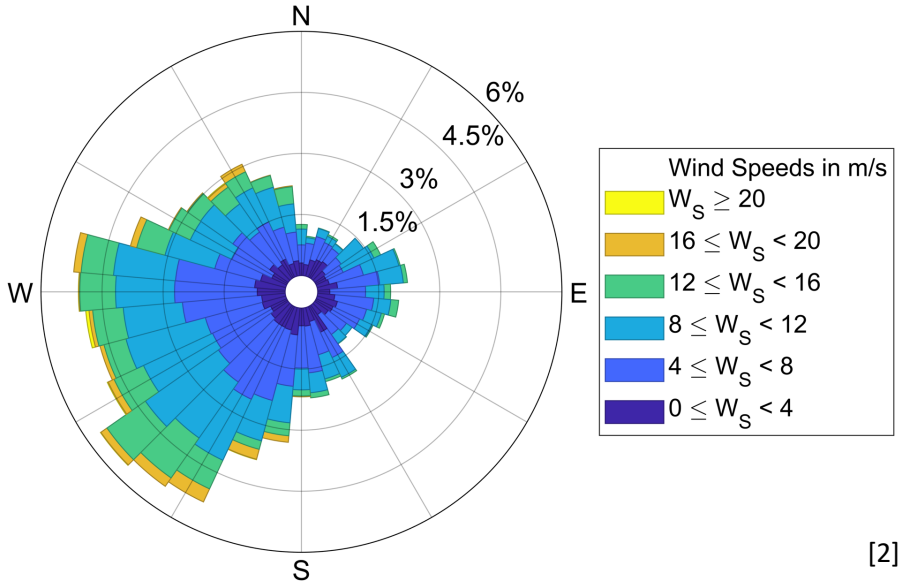
- Wave field not affected by the floater
- The floater is rigid
- Movements on the plane parallel to the sea surface are neglected.
- Floating body is located at a height z=0 with respect to the seawater level.

Methodology



Location

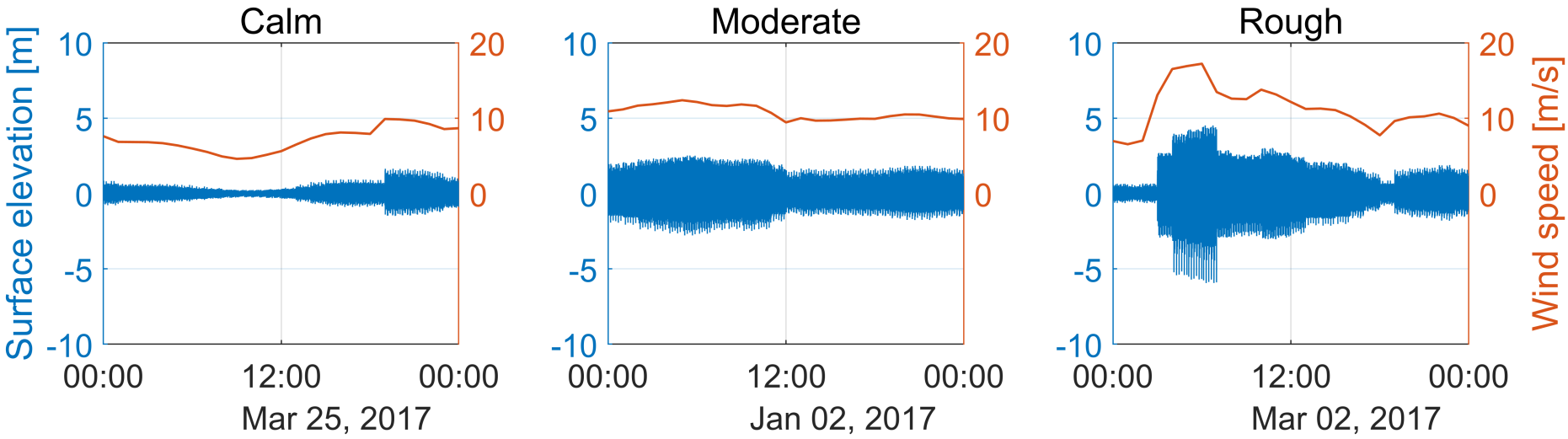
[1]



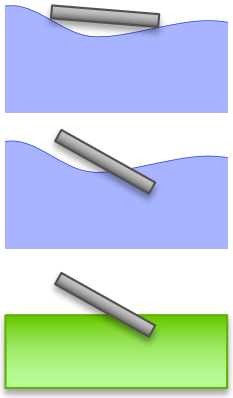
[2]

[1] Google Maps, N53.00848 E3.84971 (accessed 15/06/2022)
[2] KNMI, KNW Atlas (accessed 15/06/2022)

Sea Surface Elevation



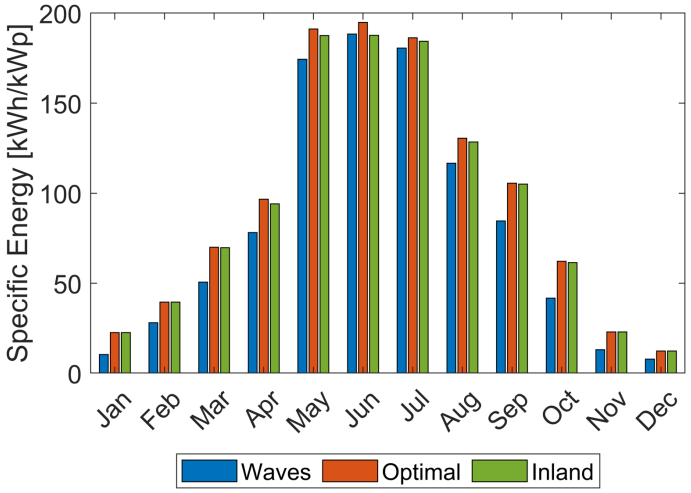
Module Temperature

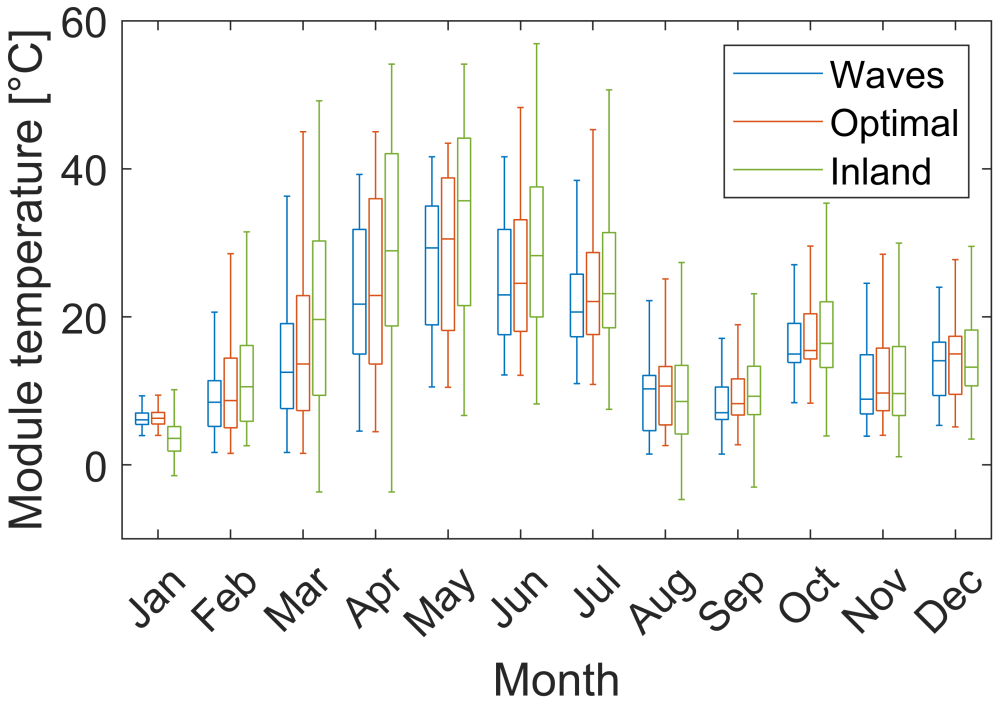


Waves

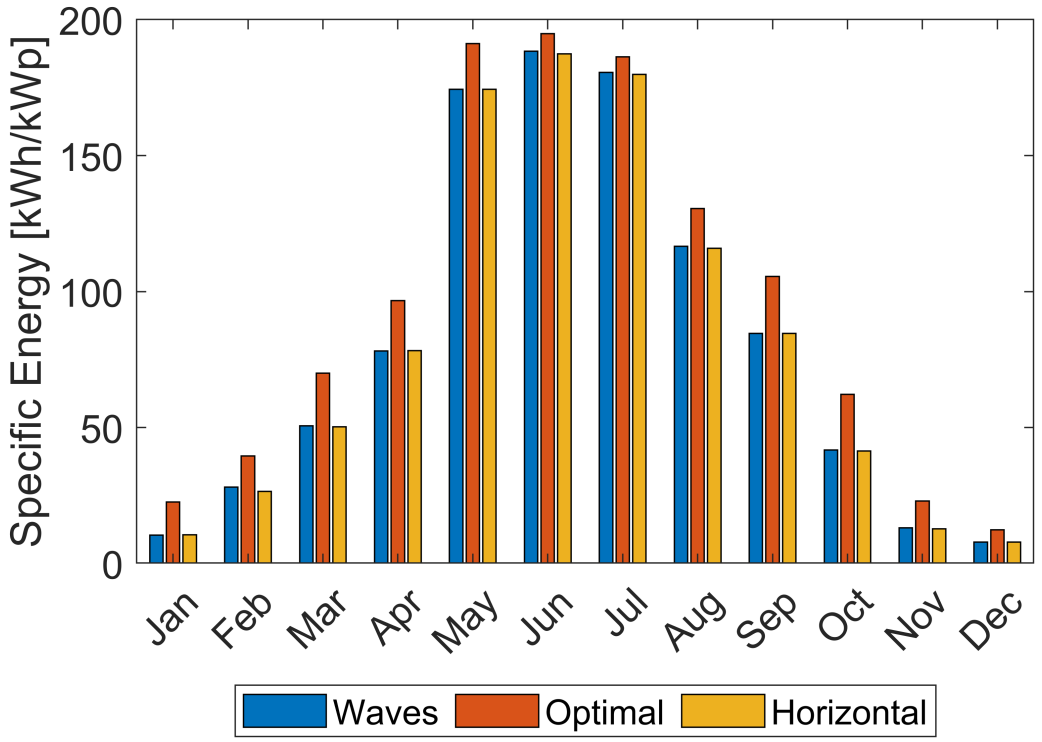
Optimal (34°)

Inland (34°)

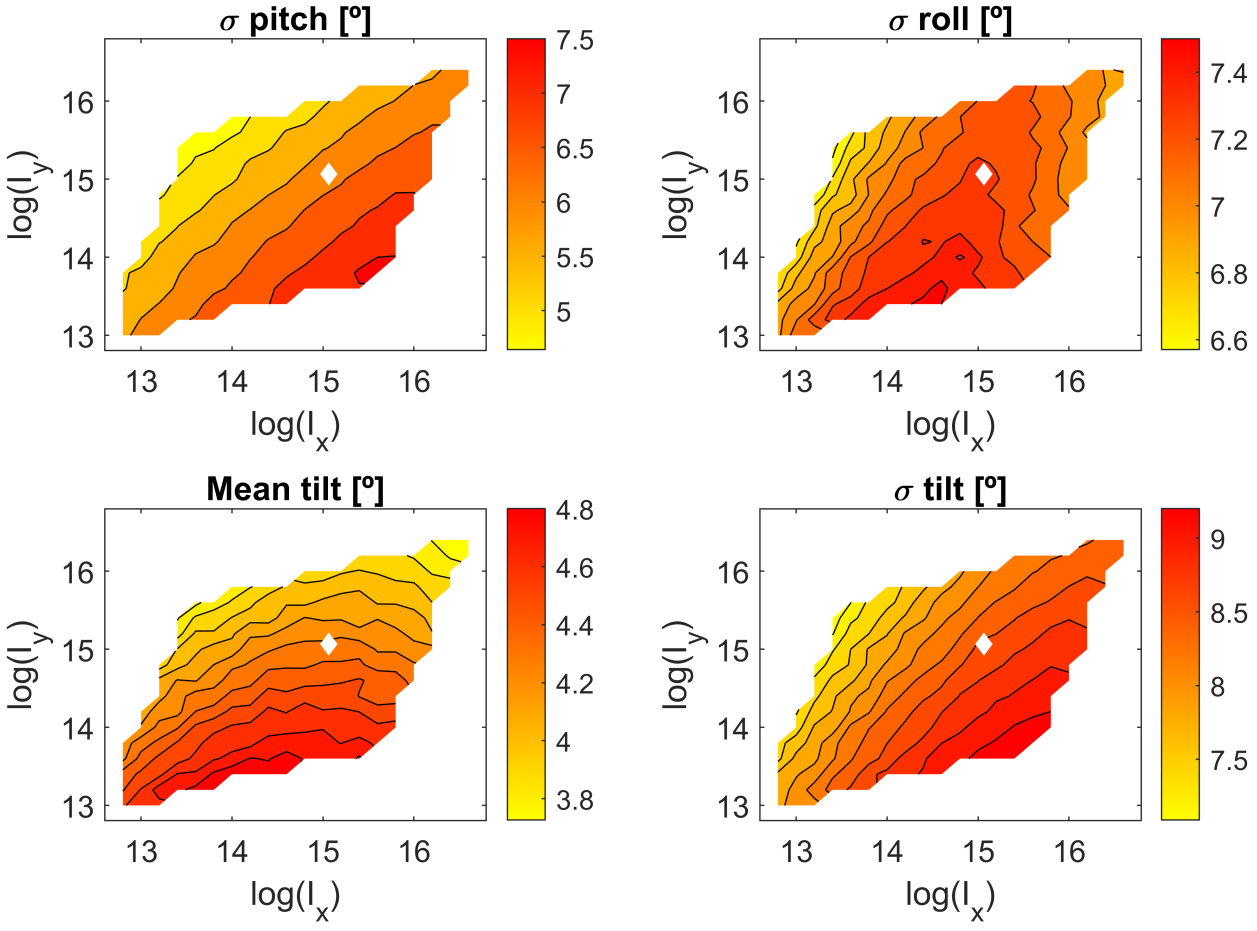




DC Yield


Specific Energy [kWh/kWp]
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Waves
Optimal
Horizontal

Sensitivity Analysis



Rectangular pontoon with the widest side aligned with the most common wind direction reduces the fluctuations