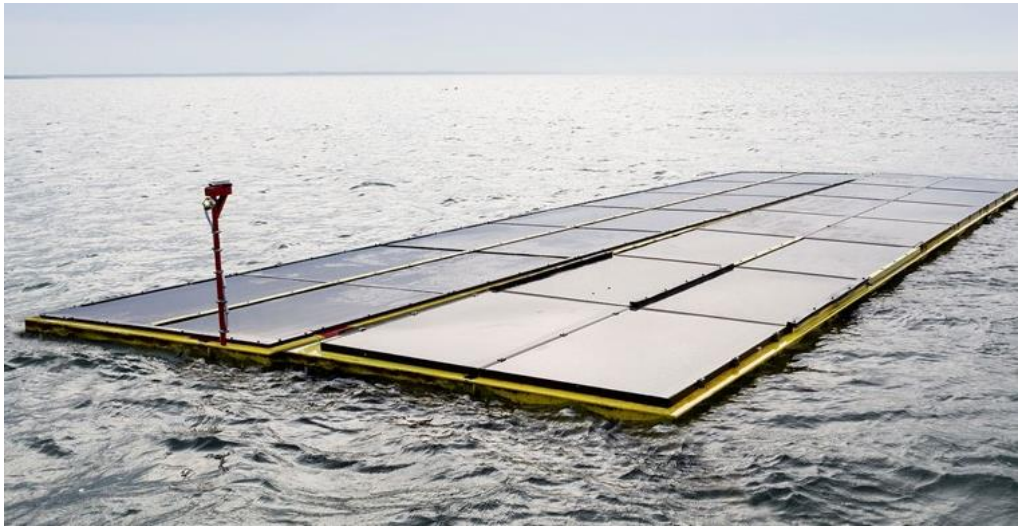

Performance of Floating PV Systems

Wilfried van Sark, Utrecht University

EUPVSEC, Lisbon, 10 September 2020 (online)

Contents

- Introduction
- Floating PV Potential
- Pros and Cons
- Performance comparison
- Conclusion and outlook

Introduction

- Deployment of solar PV
  - in the built environment (roofs, facades)
  - as large field installations

- Both require land: competition with other types of land usage (agriculture, etc.)

- Surface of the Earth consists for 71% of water (mostly oceans), and half of population lives within 100 km from oceanic shores

  → **large potential for floating PV structures**

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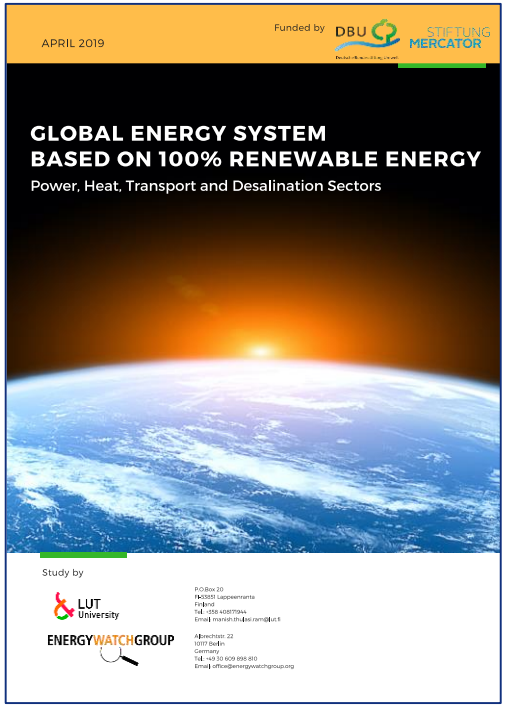
Floating PV potential

- Identified as >5 TWp global potential [Rosa-Clot, Tina, 2020]
- 100%RE scenario requires 35 TWp, all onshore [EWG, LUT, 2019]
- What if the offshore option is added?

TABLE 1.2
Technical Photovoltaic Potential for Climate Zones.

	Surfaces, km^2	Technical Power Potential, GWp	Technical Energy Potential, TWh/year
Tropical zone	1,448,031	1875	2352
Temperate zone	1,386,202	1677	1922
Cold zone	1,611,663	1715	1714
	4,445,896	**5267**	**5988**



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Example off-shore PV potential: the Netherlands

Enormous potential:
100,000 km^2, ~1% PV: 237 GWp
off-shore: 45 GWp

- Agriculture, forest, nature, recreational
- Built environment
- Infrastructure (roads)
- Water, off-shore >50%
- Part of area covered with PV

Folkerts et al., Roadmap PV systemen en toepassingen, 2017

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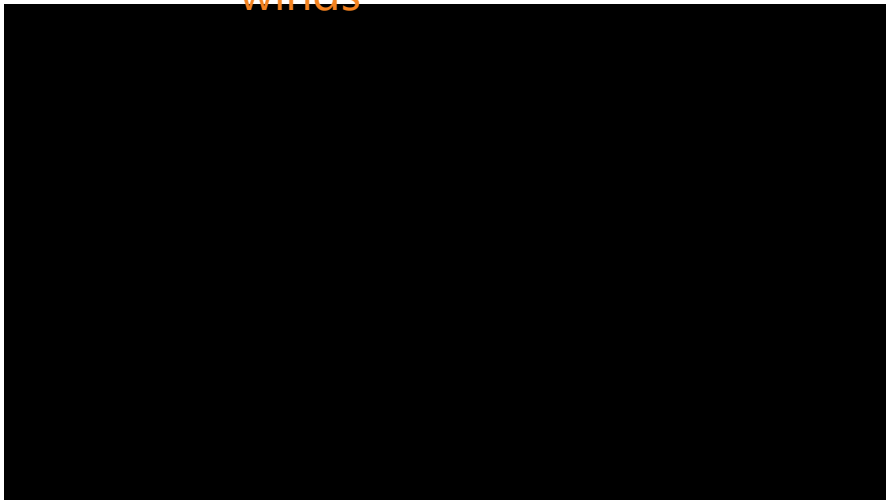
Pros and cons

- Pros
  - Massive potential
  - Better performance due to cooling of water body
    - How much?
- Cons
  - Ecological
  - Wind load
  - Cost (infrastructure)

Note:
- on-shore: sweet water, low winds
- off-shore: salty water, high winds



https://floatingsolar.nl/en/weather-risk-management-wrm/

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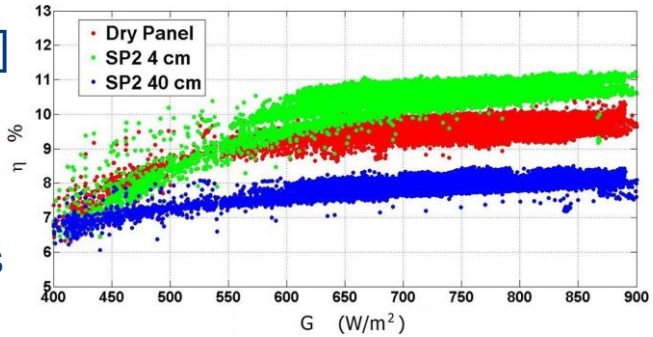
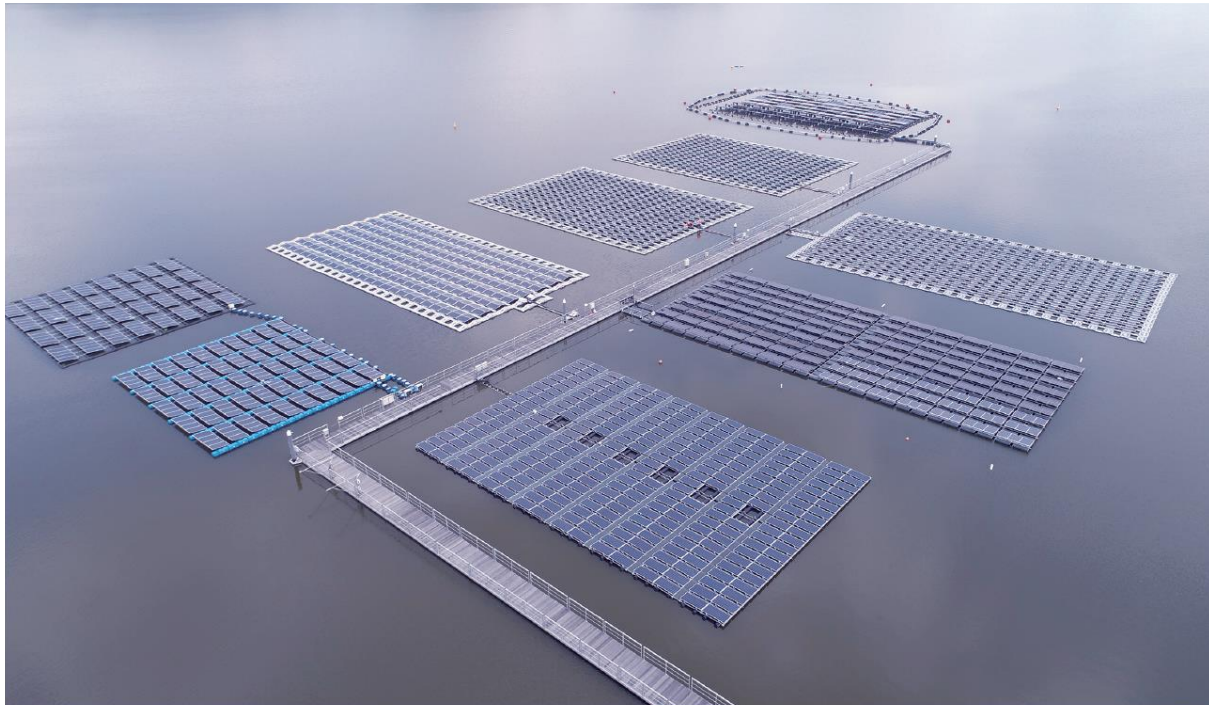
Performance

- Water body provides cooling and thus increases efficiency
  - Submerged PV panels (4 cm) [Rosa-Clot, Tina, 2018]
    - Efficiency gain: 5-15%
    - Energy yield gain: up to 15%
    - Due to cooling and less variation in panel temperatures



  - Hapcheon dam water reservoir, South Korea (100 and 500 kWp)
    - Annual yields [Suh, 2020]:
      - 1297 [2012], 1364 [2013], 1260 [2015] kWh/kWp
      - 13.5% higher yield compared to land-based system

Performance test site Singapore



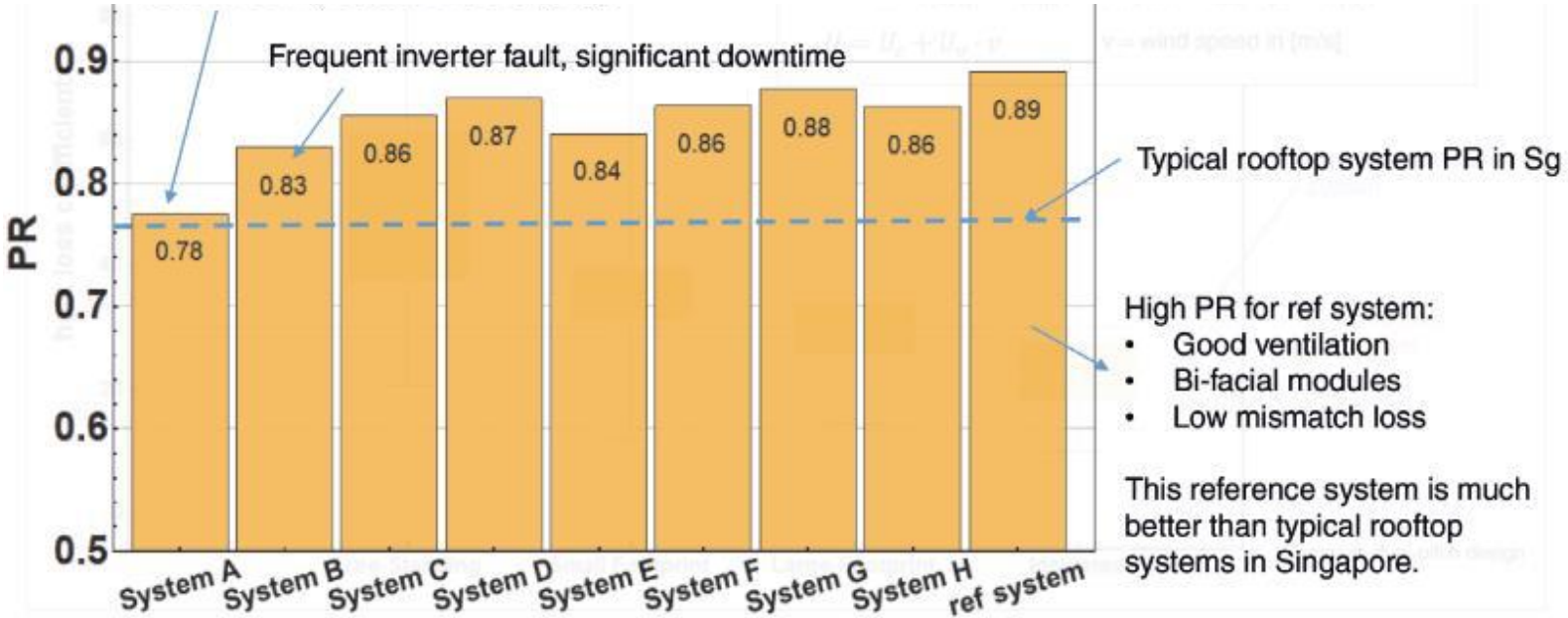






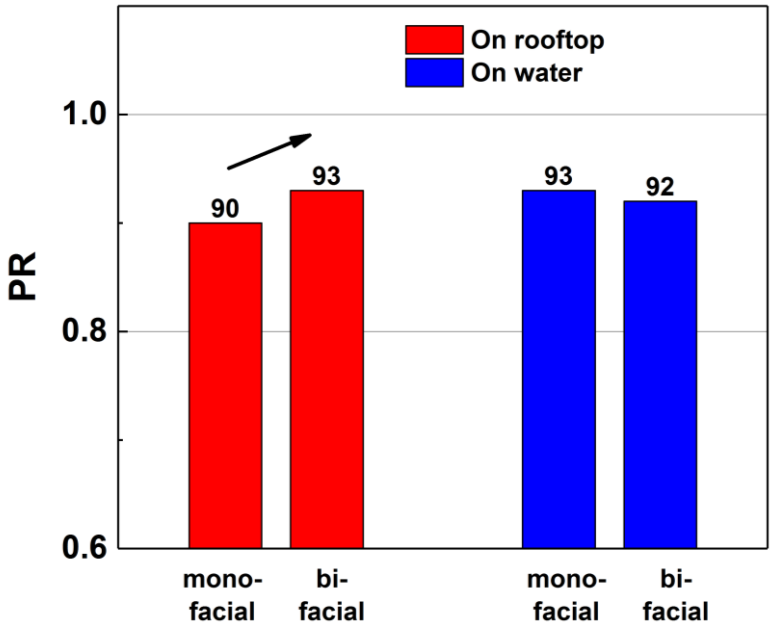

PVPS Aerial photograph and details of the Singapore Tengeh Reservoir test-bed with different Floating PV technologies [Reindl, 2018]

Performance ratio comparison

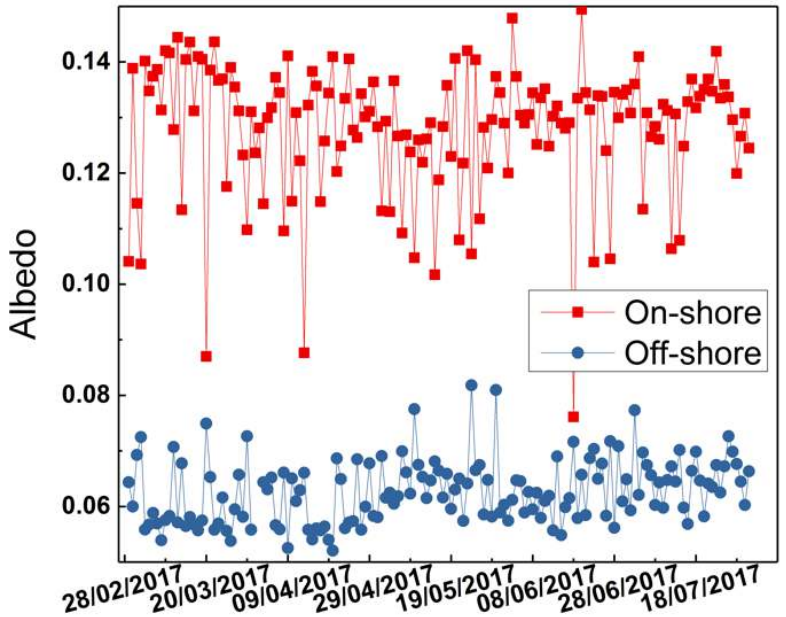


PR 10-15% higher than typical rooftop PV systems in Singapore (with PR of 75 ~ 80%) [Reindl, 2018]

Bifacial performance comparison



Daily average



Bifacial modules have similar PR for offshore and onshore conditions, due to low albedo [Reindl, 2018]

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Performance modeling

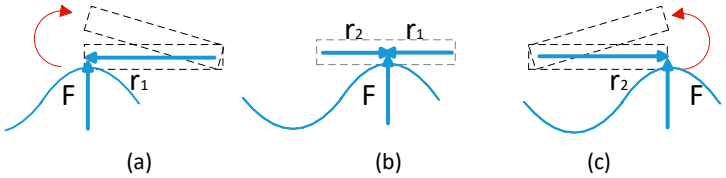
- Case study simulation
  North Sea, the Netherlands
- Floating pontoons with horizontally located solar panels
  (design: Oceans of Energy, NL)
- Performance modeling using irradiance and wind at sea
  - module temperature
  - varying tilt

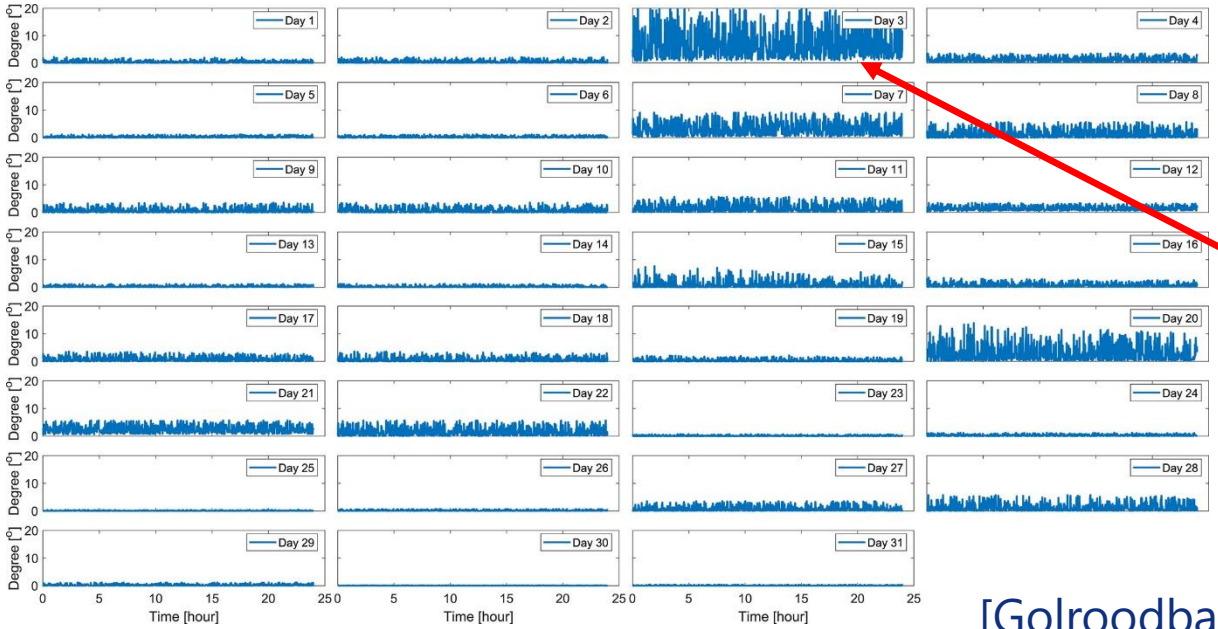
  [Golroodbari, 2020]

Oceans of Energy, NL

Tilt variation for August 2016 (example)

- Wind induces waves which affect tilt
- Using data of wind speed variation tilt variation is calculated





Tilt angles per day
- variation between 0 and 20 degrees
- mostly calm
- except Aug 3

[Golroodbari, 2020]

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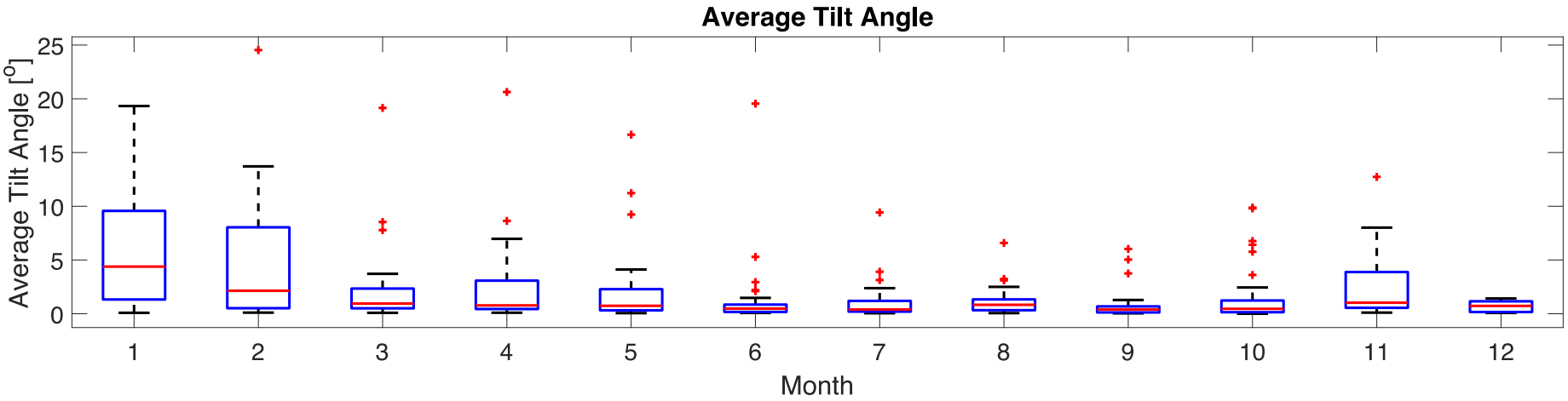
Tilt variation, montly averages

- Variation limited, larger in Jan, Feb (note: 2016)



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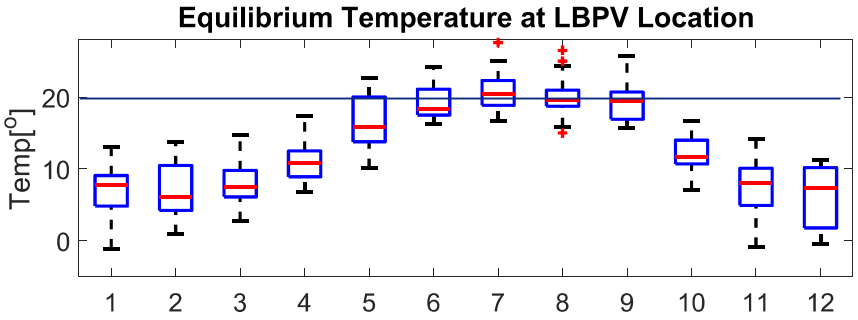
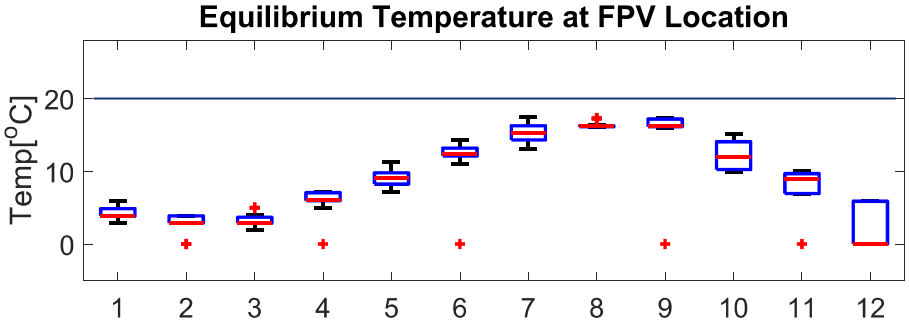
Average module temperatures





- Module temperature offshore PV is lower than on land

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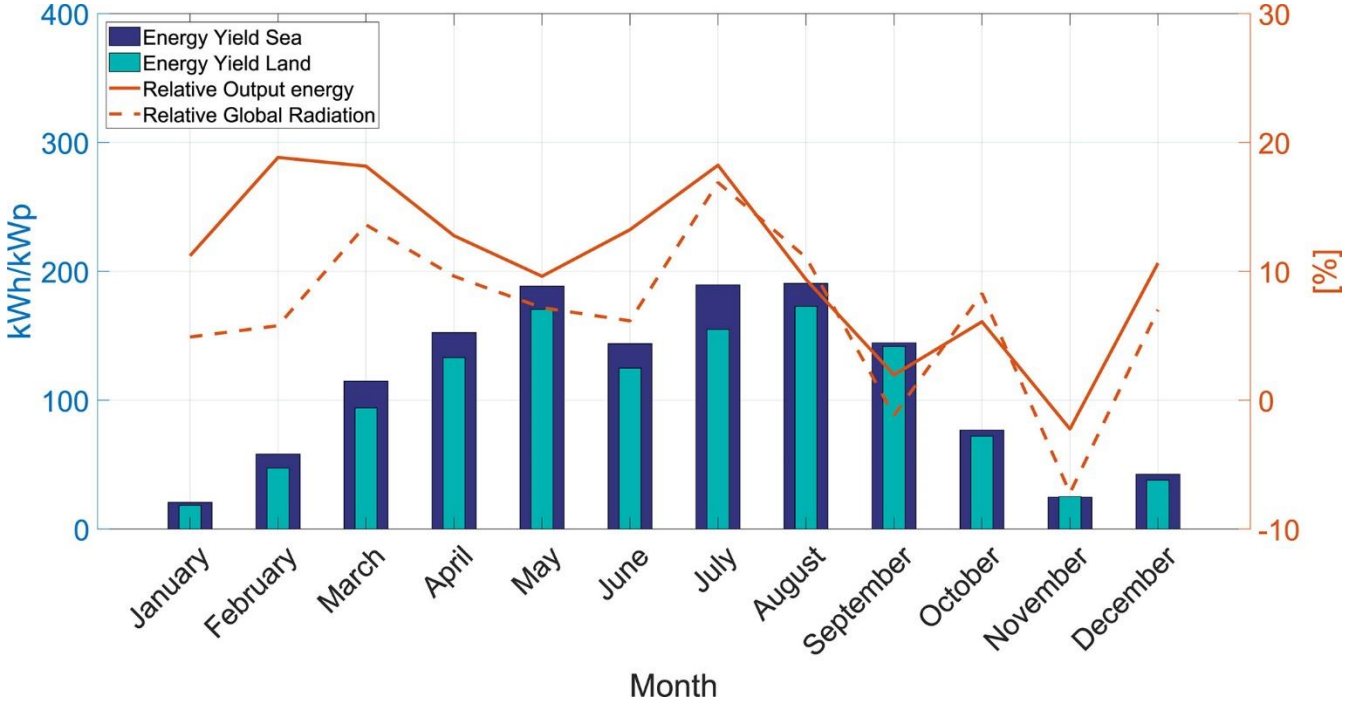
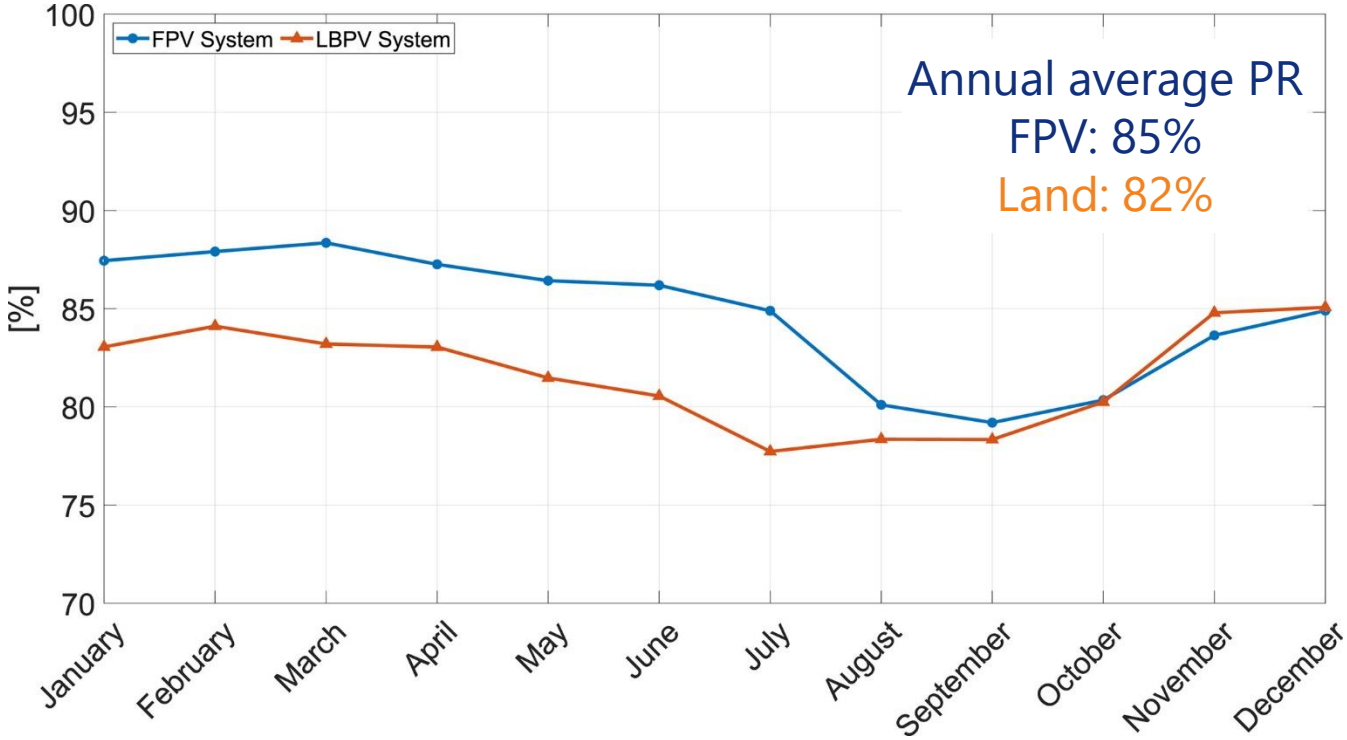
Yield advantage

- 13% higher annual yield, with monthly dependence



Performance ratio advantage

- Higher yield and higher irradiance: higher PR?

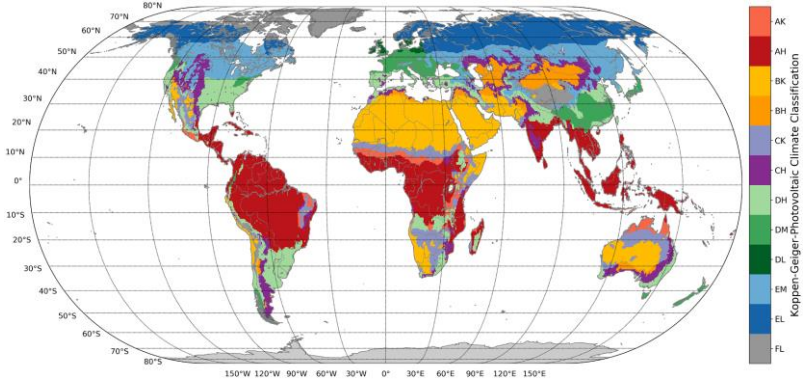


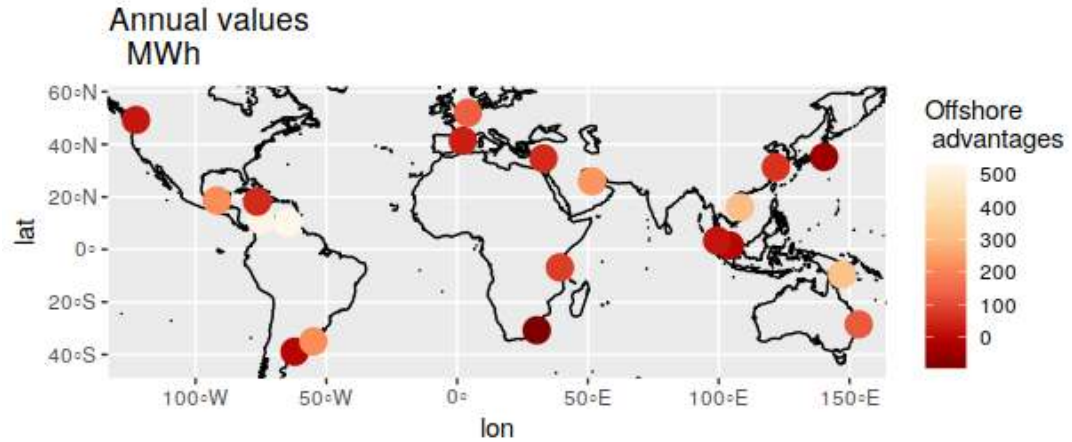
Summary of performance

- Higher performance due to cooling effect of water body
- Beneficial effect differs per geographical location
  - +13% higher yield in the Netherlands, 4% PR advantage
  - +15% in Singapore, 10-15% PR advantage
- Comparing tropics with NL:
  - Higher irradiance and higher ambient temperature lead to higher panel temperature
  - Also, higher temperature of cooling water body
  - Are cooling effects similar?

Summary of performance

- Is there a link with KG classification?
  - NO (see poster 6CV.2.34, Ayyad et al.)
  - But correlation is found between latitude, temperature and clear-sky differences for offshore and onshore sites (preliminary work)
  - Offshore advantage variation up to 30%





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Conclusion

- Floating PV performance is better than on land, due to cooling
  - Positive effect depends on geographical location
  - Verification and further R&D necessary

- Application potential
  - Integration of floating PV with other renewables
    - Hydro reservoirs
    - Offshore wind parks: allows for cable pooling, more often constant power

Thank you

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