# Bridging gaps in understanding fluid-structure interaction for offshore renewables



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# Offshore renewables

## Technologies and status of offshore wind and wave farms

# Offshore wind and wave farms

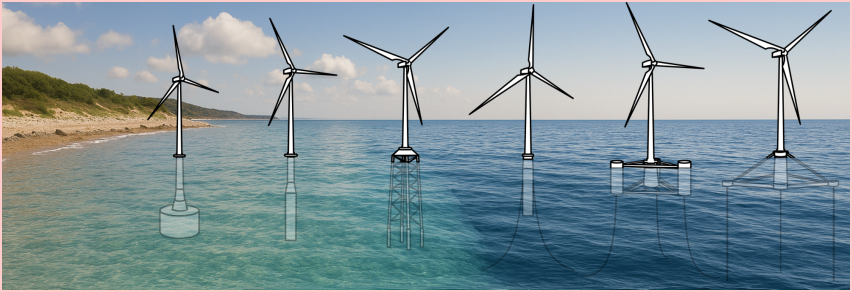
## Offshore wind technologies



Fixed: Gravity based, monopile, jacket foundations.
Suitable for depths $< 40$ m (monopiles) or $< 70$ m (jacket).

# Offshore wind and wave farms

## Offshore wind technologies

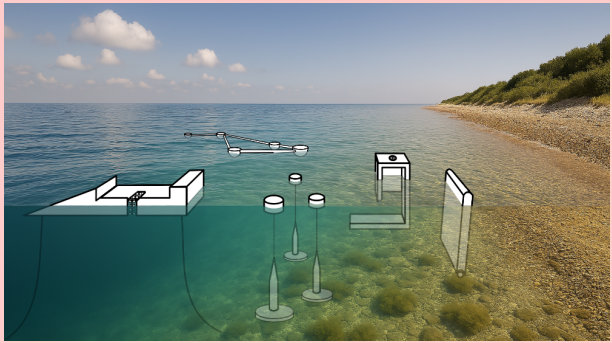


**Fixed:** Gravity based, monopile, jacket foundations.
Suitable for depths $< 40$ m (monopiles) or $< 70$ m (jacket).

**Floating:** Spar buoys, semi-submersible, tension leg platforms.
For installations in depths $> 60$ m.

# Offshore wind and wave farms

## Wave energy technologies



- Wave energy converters convert energy in ocean waves into electricity
- Hundreds of concepts: differing in size, materials, power take-off mechanisms, conversion systems, installation location, dynamics, ...
- Overtopping, attenuator, point-absorber, oscillating water column, oscillating wave surge converter

# Offshore wind and wave farms

## Status offshore wind



- First offshore wind farm installed in 1991 in Denmark: 11 $\times$ 450 kW turbines.
- Offshore wind capacity today over 83 GW, with 67% installed since 2020.
- Most installations in recent years in the Asia-Pacific region.
- Hywind Scotland first floating offshore wind farm installed in 2017.

# Offshore wind and wave farms

Status wave power




- No convergence on technologies.
- Lower commercial & technical maturity than offshore wind.
- Several prototypes $20 - 500$ kW demonstrated offshore.

# Offshore wind and wave farms

Status wave power



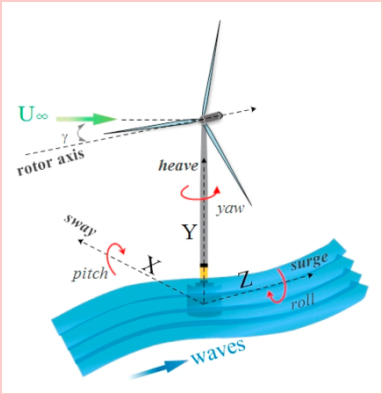
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# Challenge

## Fluid-structure interaction affects the performance of offshore renewables

# Fluid-structure interaction

Impact on offshore renewables

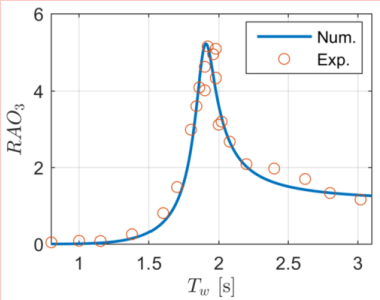



[Guo et al., Renewable Energy (2022)]

- **Wind power:** Platform motion affects
  - aerodynamics [Cai et al. (2024); Xiao et al. (2025)] incl. blade deformation [Huang et al. (2025)] and wakes [Kuang et al. (2022); Wang et al. (2025)] ⇒ farm design and output
  - stability [Guo et al. (2022)],
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# Fluid-structure interaction

Impact on offshore renewables




[Chen et al. (2018)]

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- **Wave power:** *designed* for FSI with waves
  - Control seeks to optimize FSI
  - Constructive vs destructive hydrodynamic farm interaction confirmed
  - Dynamical instabilities can severely alter performance

# Approaches

## How to assess the fluid-structure interaction accurately?

# Fluid-structure interaction

Methods of different fidelity



# Fluid-structure interaction

Methods of different fidelity



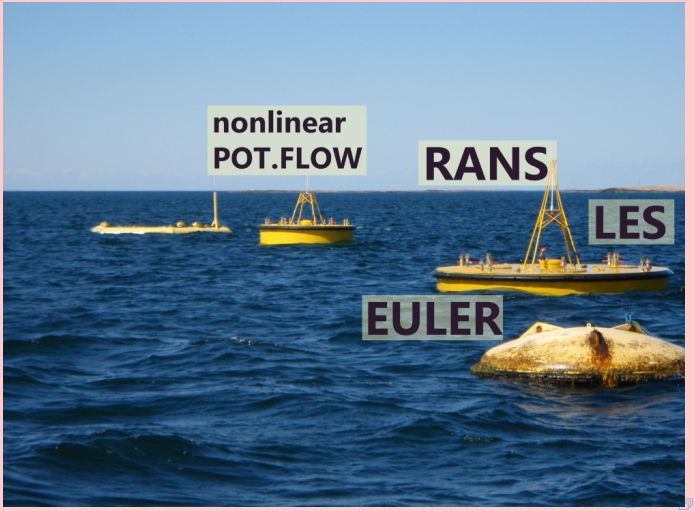
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Methods of different fidelity



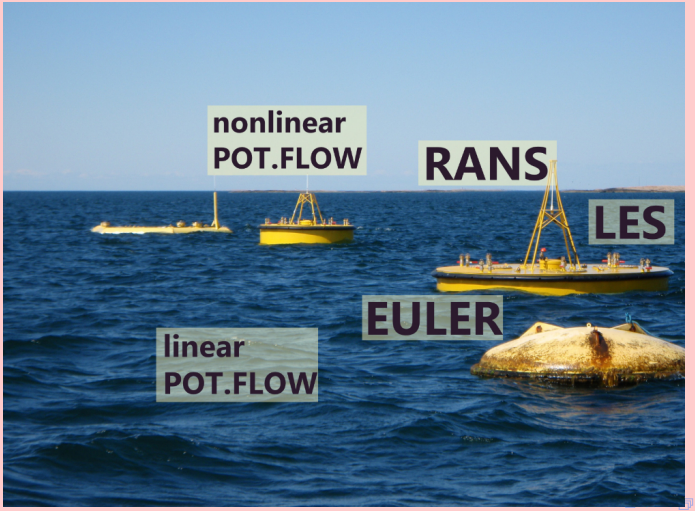
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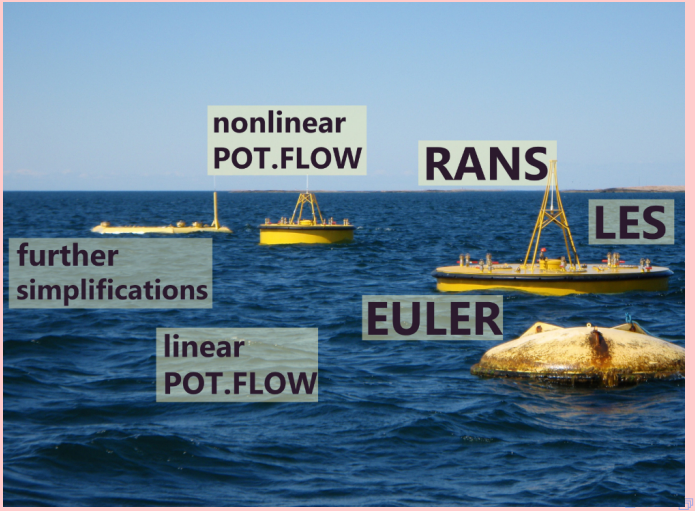
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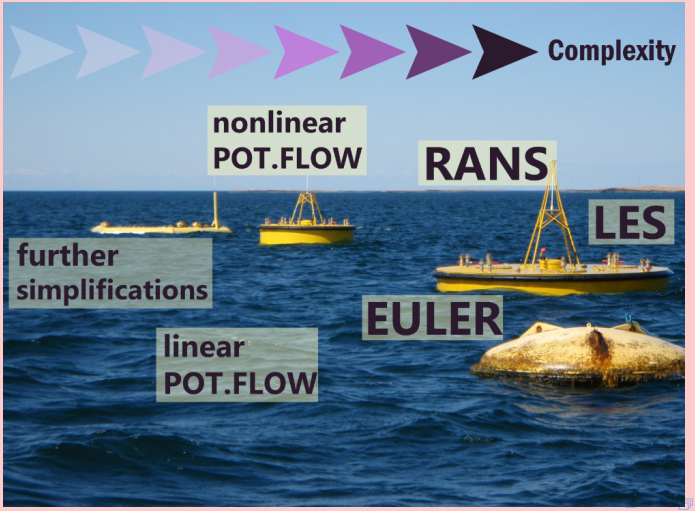
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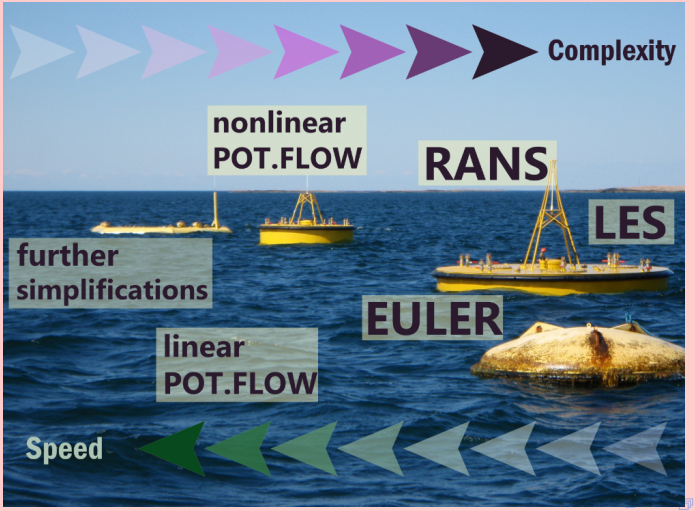
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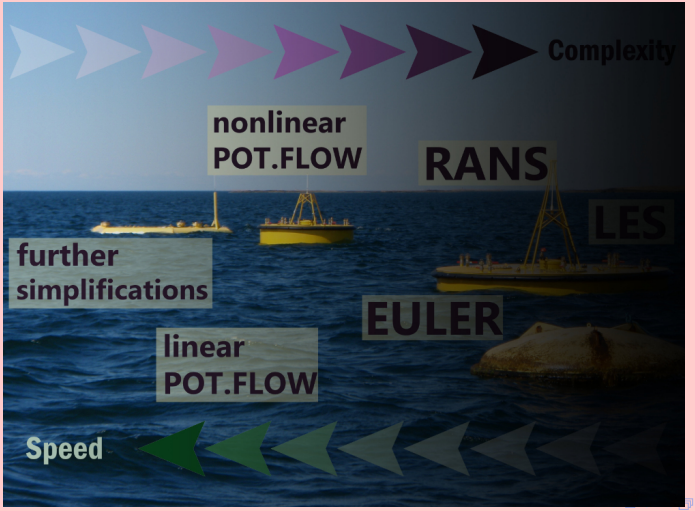
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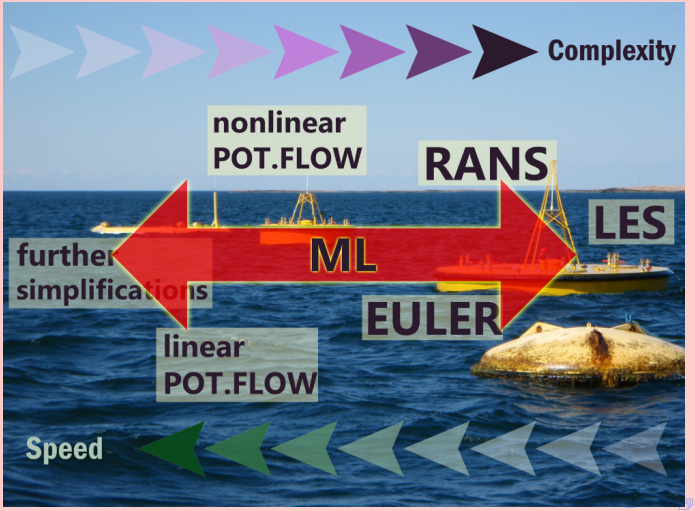
# Data-driven methods

Advancing capabilities



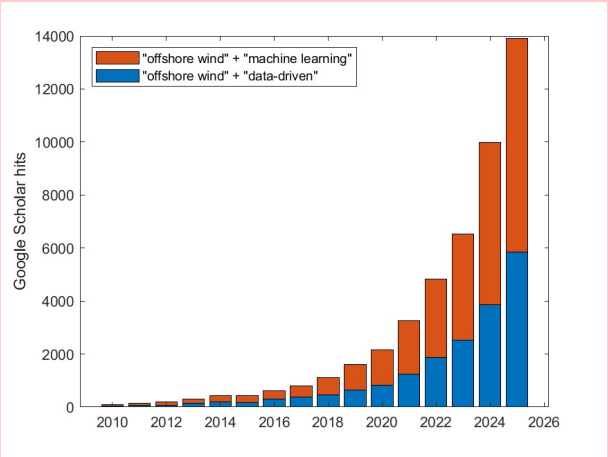
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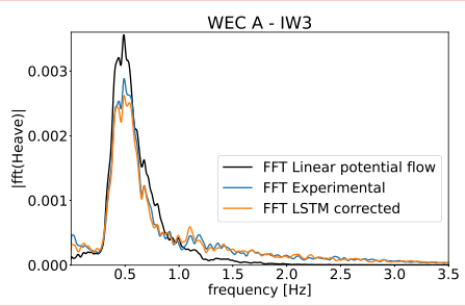
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Advancing capabilities



# Examples

Predicting dynamics using neural networks



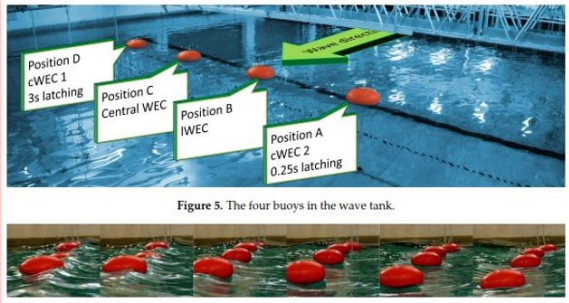




**Figure 5.** The four buoys in the wave tank.

- Surrogate models can predict complexities not covered by low-fidelity models [Stavropoulou et al. 2025]
- Informed use of CFD reduces need for training data [Katsidoniotaki et al. 2025; Tagliafierro et al. 2026]
- Model-free collaborative control to enhance farm performance [Thomas et al. 2018]
- Dynamical instabilities predicted by data-driven methods [Göteman et al. 2026; Rose-Butcher et al. 2026]

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**Some take-aways:**

Emerging technologies. Wave energy and (floating) offshore wind have great potential, but accurate models are needed to advance the technical maturity.

Limited knowledge. *No available methods* capable of modelling coupled multi-physics systems (incl. wave-structure interaction) of large offshore RES farms.

Utilize all approaches. Combining novel low-fidelity models (large farms), high-fidelity data (CFD or experiments) and ML can advance current capabilities.



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**Thank you for your attention!**

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