Geotechnics for Offshore Wind

Setting the scene – Phil Watson

A developer's perspective of geotechnics for offshore wind – Elisabeth Palix

An overview of ‘new’ challenges facing offshore wind – Zack Westgate

Geotechnical research to support offshore wind – Christelle Abadie

Close – Phil Watson

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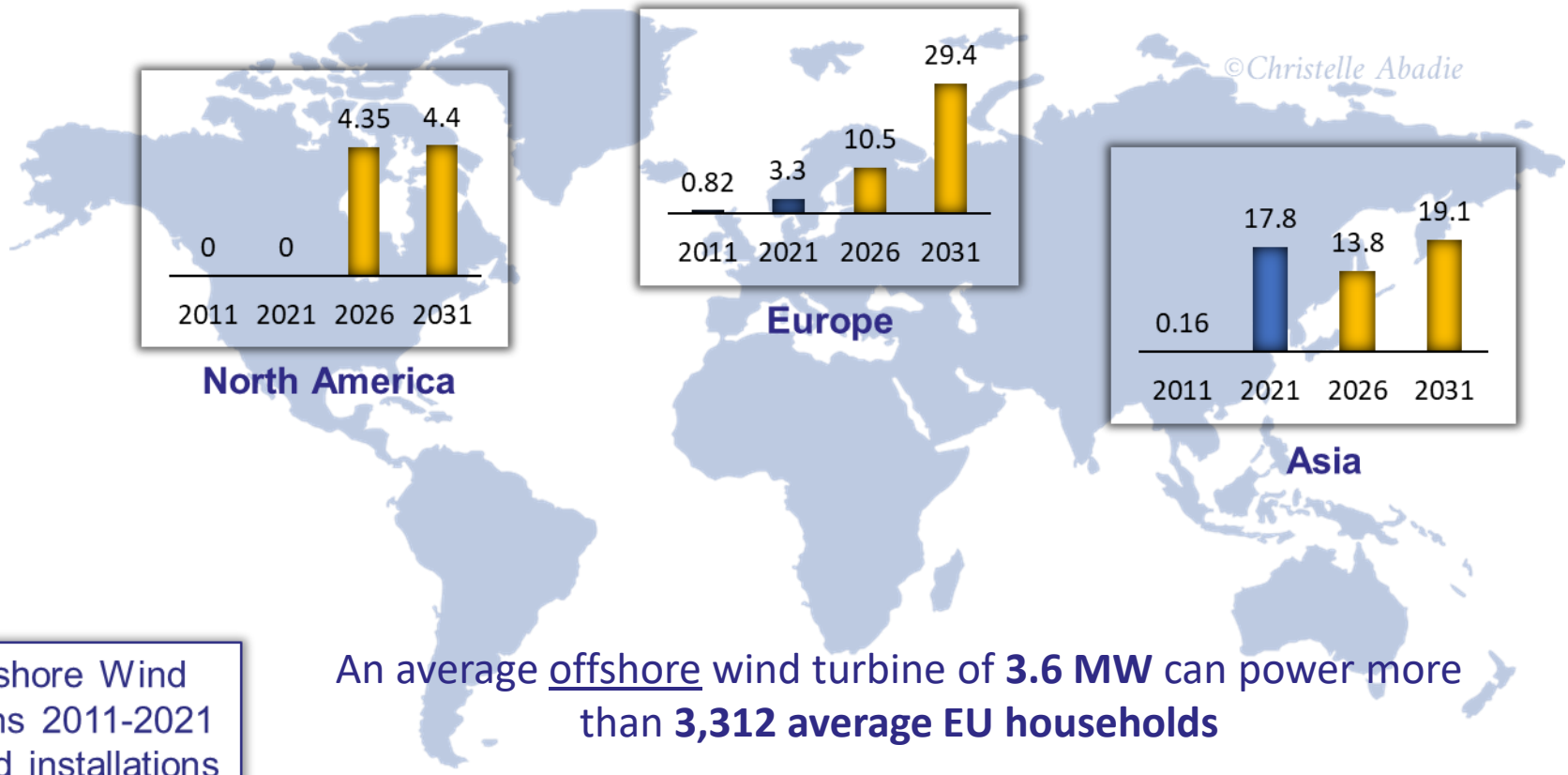
Motivation and Objectives



New Offshore Wind Installations 2011-2021 & predicted installations for 2026 and 2031 **(GW)**

An average offshore wind turbine of **3.6 MW** can power more than **3,312 average EU households**

For comparison: An average onshore wind turbine with a capacity of 2.5–3 MW can supply 1,500 average EU households with electricity

Offshore wind expansion:

- Reduce costs
- Extend service life
- Bring further offshore
- Design for larger turbines
- Adapt for new world locations

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Motivation and Objectives

Roles of R&D:

- Permit the development of new and improved design methods
- Enable the development of new foundation systems
- Verify foundation design through testing and numerical modelling

Challenges:

- Testing is difficult with large-scale field tests offshore nearly impossible
- Numerical modelling is computationally expensive and requires thorough validation against experimental database

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Research to support offshore wind

First Stages of the Research

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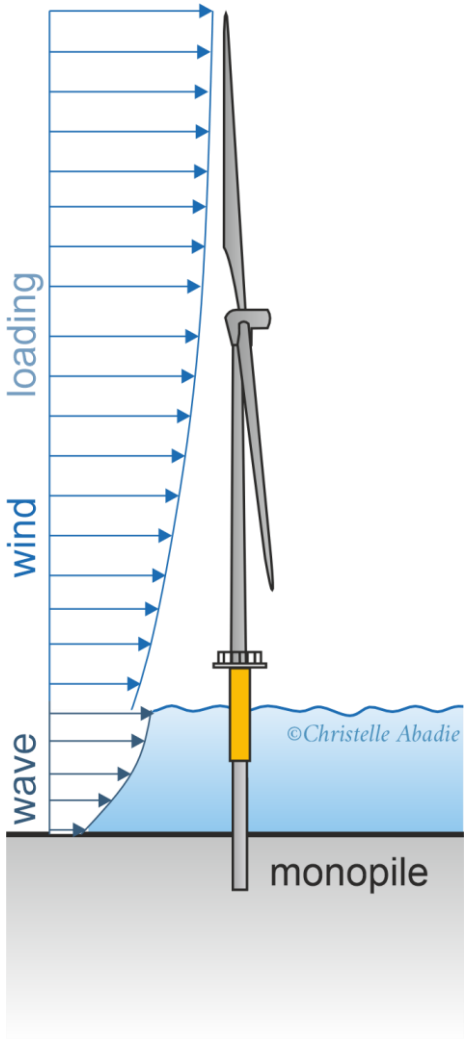
Establish Monopile Design Method

≈ early 2000s - 2017

Enable commercial viability of offshore wind in Northern Europe waters

- Understand the behaviour of large diameter monopiles under lateral loading
- Move away from traditional *p-y* curves and propose new and robust design methods to predict foundation capacity and small strain stiffness:
  - » permit integration with structural design software
  - » accurately predict turbine natural frequency
- Establish the first models to account for long-term cyclic loading



Offshore wind expansion:

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Offshore wind power cheaper than new nuclear

By Roger Harrabin
BBC environment analyst

11 September 2017 | Business

Share

Bigger turbines, higher voltage cables and lower cost foundations as well as growth in the UK supply chain and the downturn in the oil and gas industry have all contributed to falling prices.

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Progress on bottom-fixed foundations

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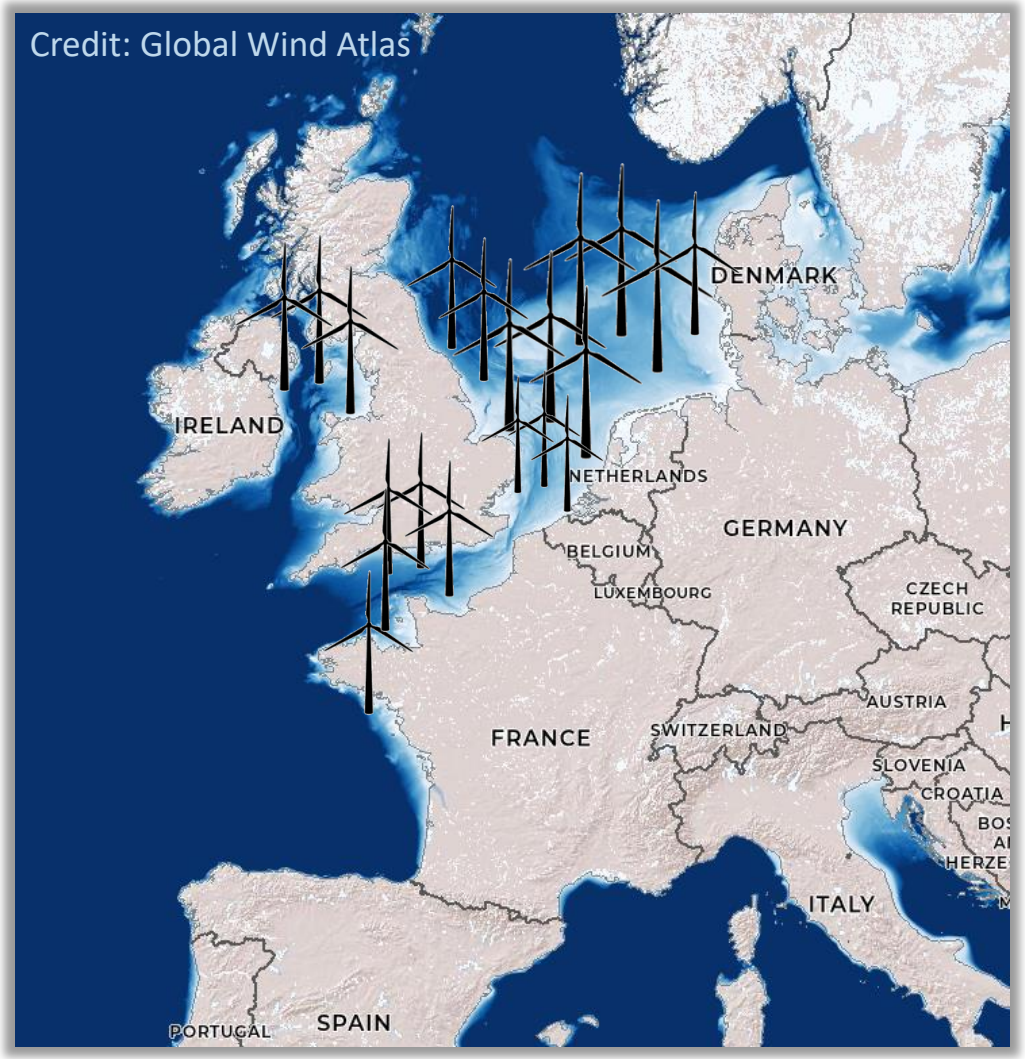
➢ *Subsidy-free offshore wind (bottom-fixed)*

Establish Monopile Design Method	Monopile Design Optimisation	Gravity, Jacket Piles & Caissons
≈ early 2000s - 2017	≈ 2010s – Today	≈ 2010s - Today
Enable commercial viability of offshore wind in Northern Europe waters	Improve design robustness and installation methods	Provide a wider foundation mix to adapt to large range of offshore environnements



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Research to support offshore wind

Improving monopile design

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➢ *Subsidy-free offshore wind (bottom-fixed)*

Establish Monopile Design Method

≈ early 2000s - 2017

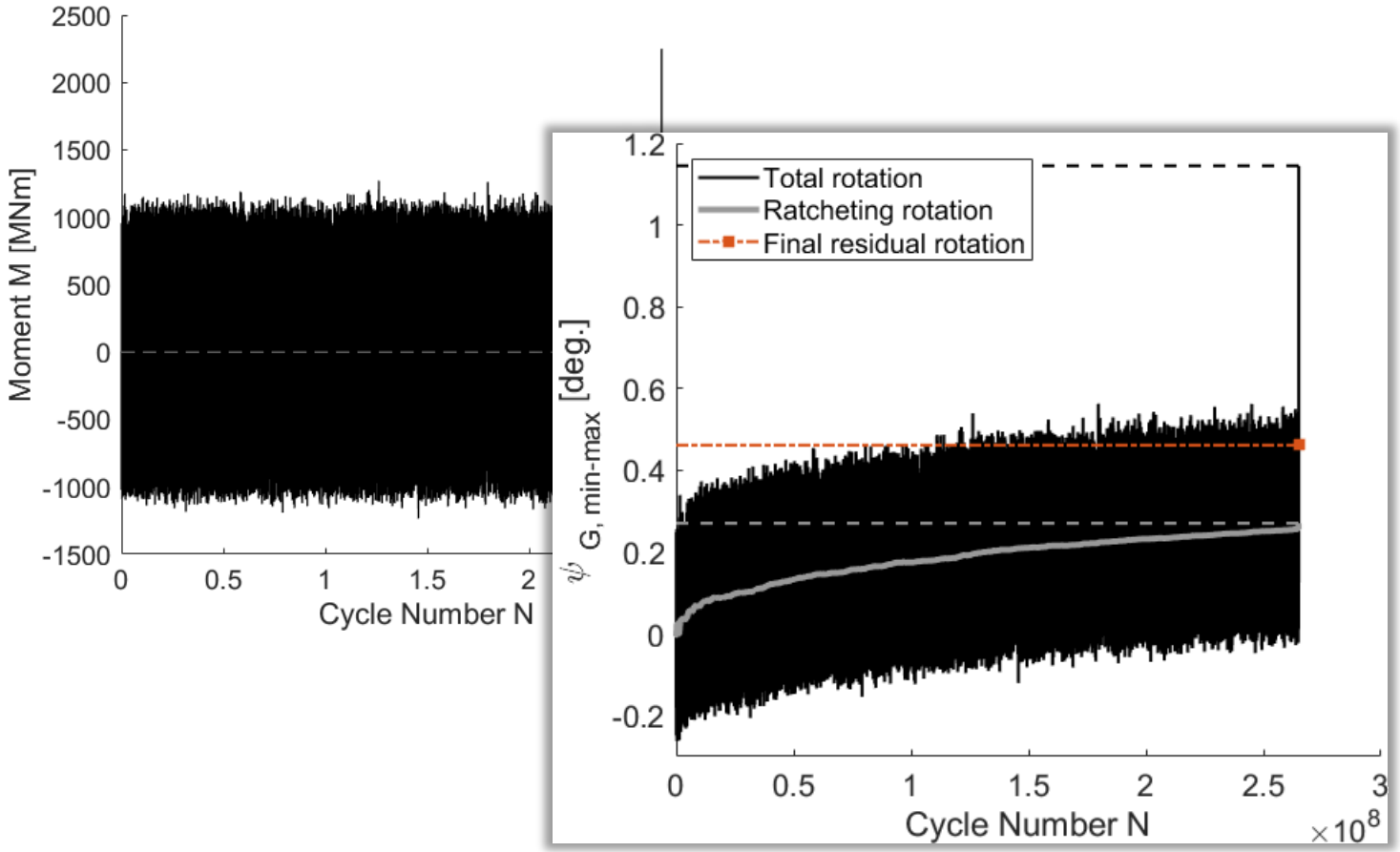
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation

≈ 2010s – Today

Improve design robustness and installation methods

■ Refine the models for cyclic loading
(e.g. NGI cyclic diagrams, HARM, MIDAS, PICASO, Hysand…)



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Abadie, C.N., Beuckelaers, W.J.A.P., Byrne, B.W., Houlsby, G.T., Burd, H.J. & McAdam, R.A. (2023)
Modelling Lifetime Performance of Monopile Foundations for Offshore Wind Applications
Journal of Geotechnical and Geoenvironmental Engineering, ASCE

Research to support offshore wind

Improving monopile design

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- Refine the models for cyclic loading
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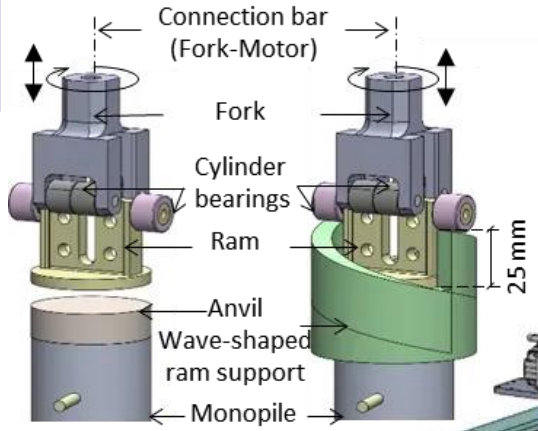
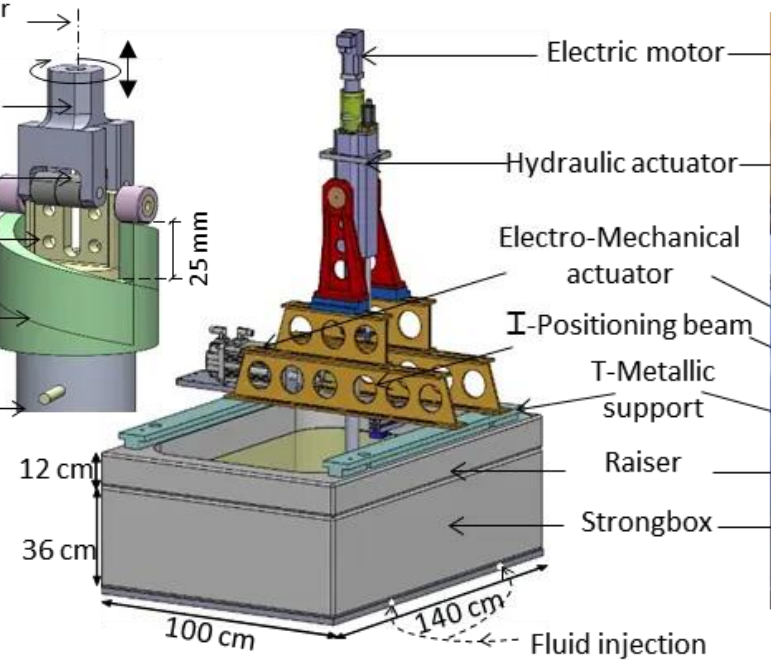
- Improve installation methods to reduce risks associated with installation and the environmental impact of pile driving
  (e.g. Blue Piling, Gentle Pile Driving, Development of pile hammers and vibro hammers for centrifuge modelling)





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Maatouk, S., Blanc, M., Thorel, L. (2022)
Impact driving of monopiles in centrifuge: effect on the lateral response in sand
International Journal of Physical Modelling in Geotechnics

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Improving monopile design

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Monopile Design Optimisation

≈ 2010s – Today

Improve design robustness and installation methods

- Refine the models for cyclic loading
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- Improve installation methods to reduce risks associated with installation and the environmental impact of pile driving
  (e.g. Blue Piling, Gentle Pile Driving, Development of pile hammers and vibro hammers for centrifuge modelling)
- Tackle installation and design in weak rocks, chalk
  (e.g. ALPACA, EDF onshore field testing)

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Elisabeth Palix – Offshore technical lead – APAC
First part of this TC209 talk: A developer's perspective of geotechnics for offshore wind

Research to support offshore wind

Gravity Base Foundations

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Establish Monopile Design Method	Monopile Design Optimisation	Gravity, Jacket Piles & Caissons
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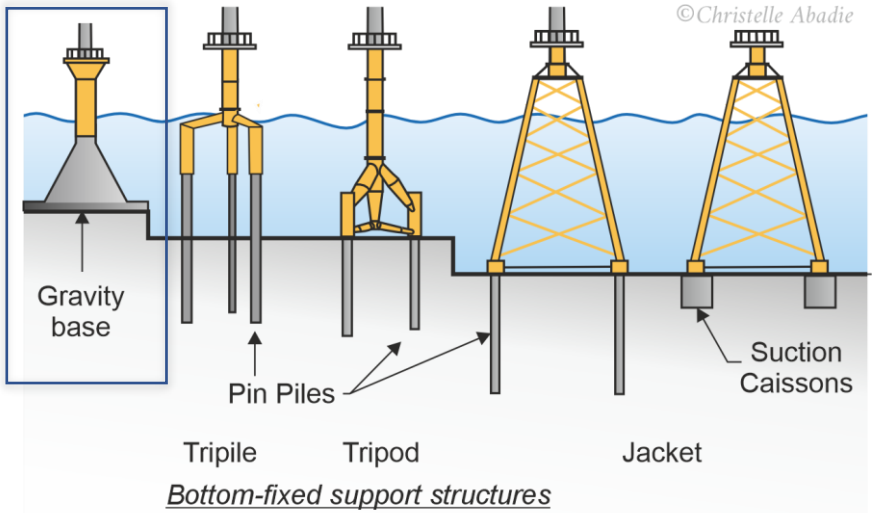

- Design of gravity base foundations

Photo of 31 m diameter gravity-base foundations for the support of 71 turbines in Fécamp, France
(©Parc éolien en mer de Fécamp - Laurent Critot)

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Gravity Base Foundations

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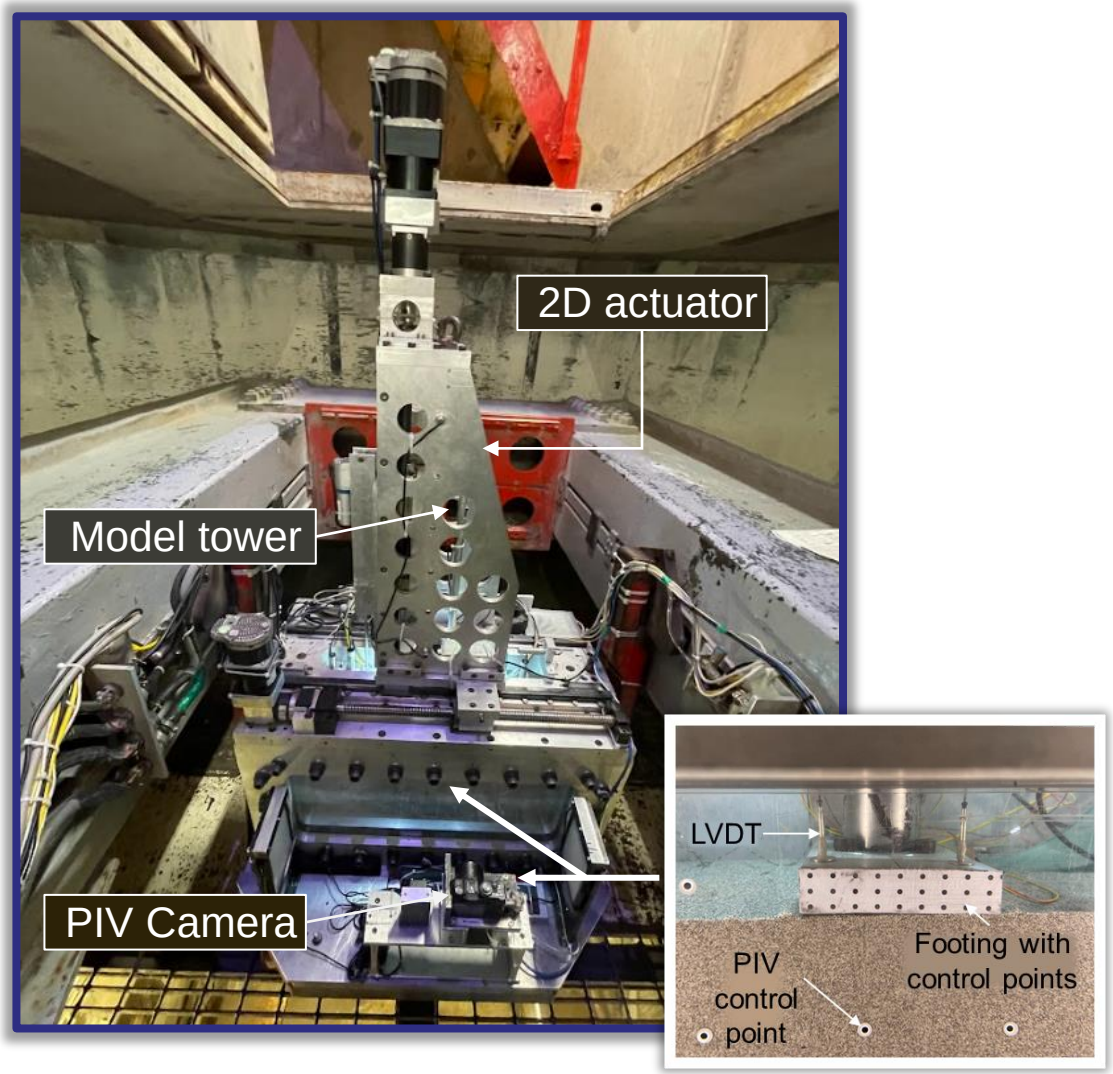

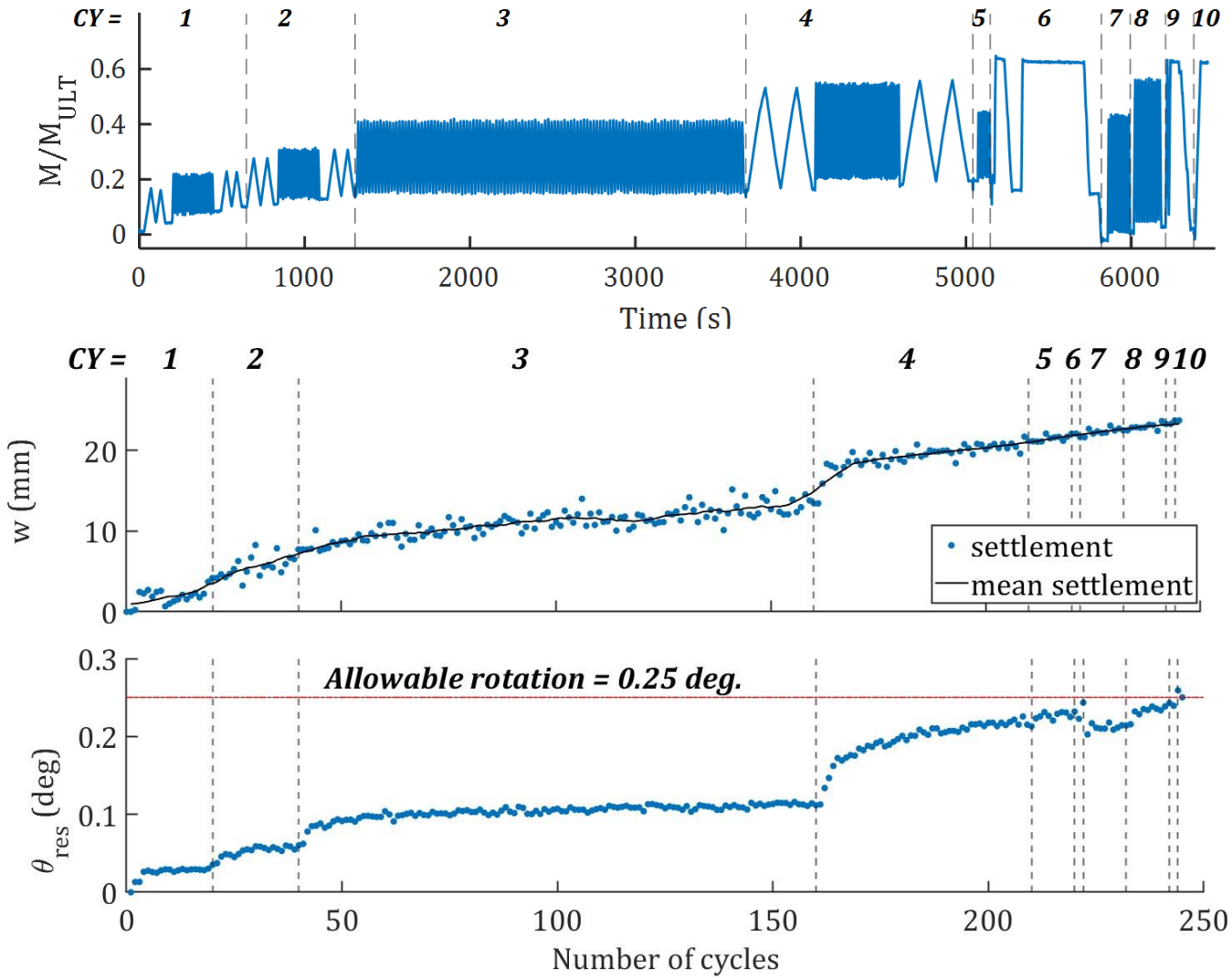

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Ifeobu, C.U., Abadie, C.N. and Haigh, S.K. (2023)
Young Scientist Award - Cyclic response of shallow onshore wind turbine foundations resting on dense sand
Geotechnics for Sustainable Infrastructure Development - Geotec Hanoi 2023

Research to support offshore wind

Suction Bucket Jackets (SBJ)

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➢ *Subsidy-free offshore wind (bottom-fixed)*

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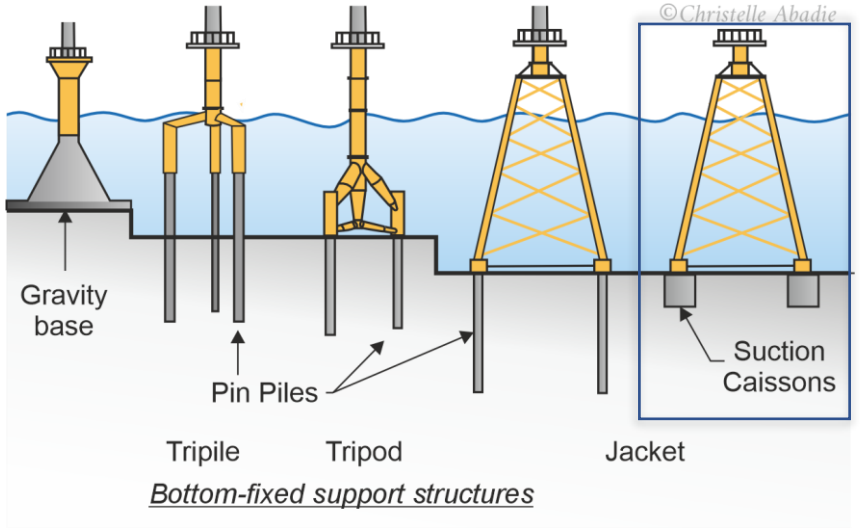

- Design of gravity base foundations
- Design of Suction Bucket Jackets (SBJ)

450MW Borkum Riffgrund 2 wind farm, Germany – built in 2018 – credit: Ørsted

Offshore Wind Accelerator

Suction Installed Caisson Foundations for Offshore Wind: Design Guidelines

February 2019

CARBON TRUST · The Scottish Government · Ørsted · EnBW · e·on · innogy

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Improving support structure design

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➢ *Subsidy-free offshore wind (bottom-fixed)*

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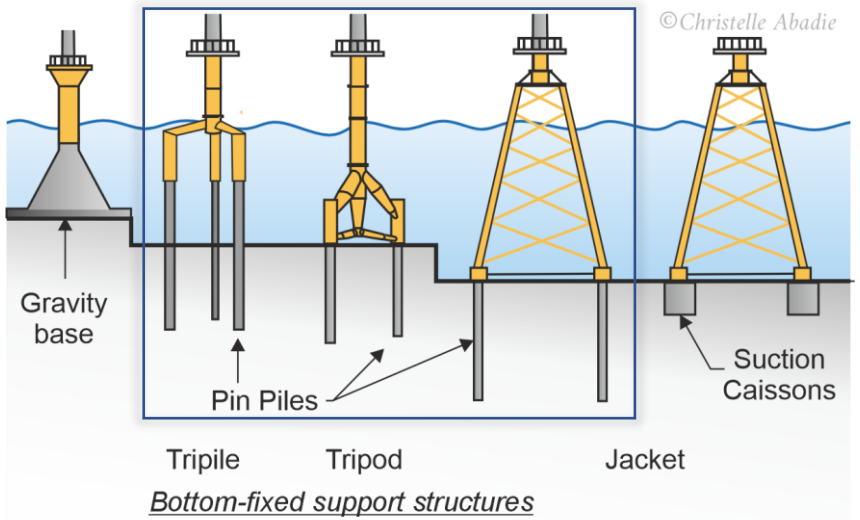

Bottom-fixed support structures

- Design of gravity base foundations
- Design of Suction Bucket Jackets (SBJ)
- Design of jacket piles
- Introduce monitoring and AI techniques to permit more efficient dans safer maintenance of wind farms

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Progress to date

➢ *Subsidy-free offshore wind (bottom-fixed)*

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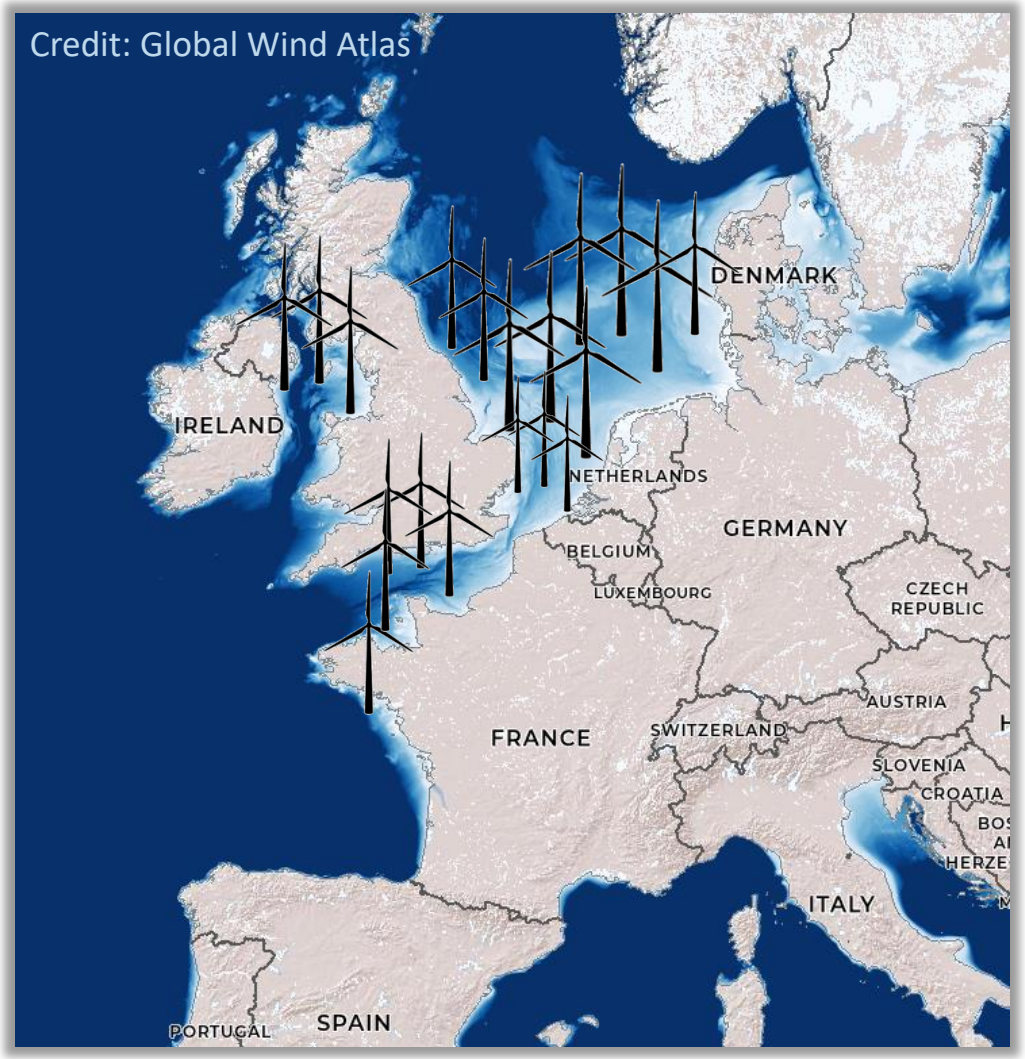

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Progress to date

➢ *Subsidy-free offshore wind (bottom-fixed)*

➢ *Expansion to East Asia and America*

Establish Monopile Design Method	Monopile Design Optimisation	Gravity, Jacket Piles & Caissons	New Site Locations
≈ early 2000s - 2017	≈ 2010s – Today	≈ 2010s - Today	≈ 2018 – 2030?
Enable commercial viability of offshore wind in Northern Europe waters	Improve design robustness and installation methods	Provide a wider foundation mix to adapt to large range of offshore environnements	Extend design methods to rest of the world, with different soil conditions and geological hazards

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Offshore wind world expansion

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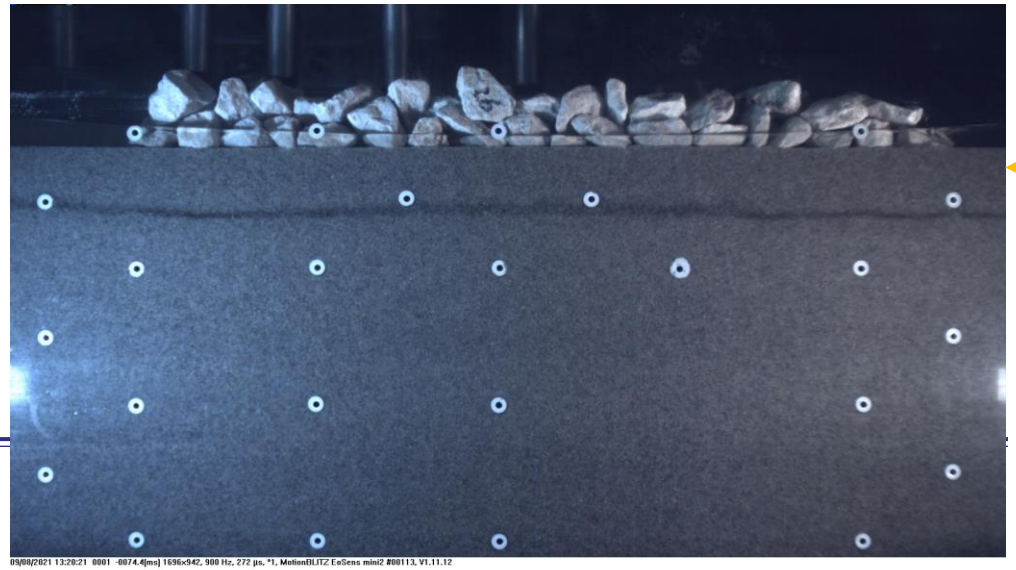
Investigate new and challenging soil conditions: carbonate soils, boulders, glauconite (PIGS project)

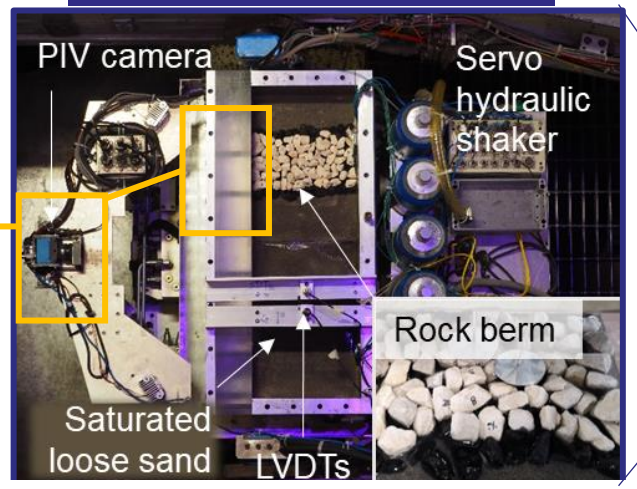
Improved site investigation and integrated design approaches to reduce geotechnical risks (e.g. pile run)

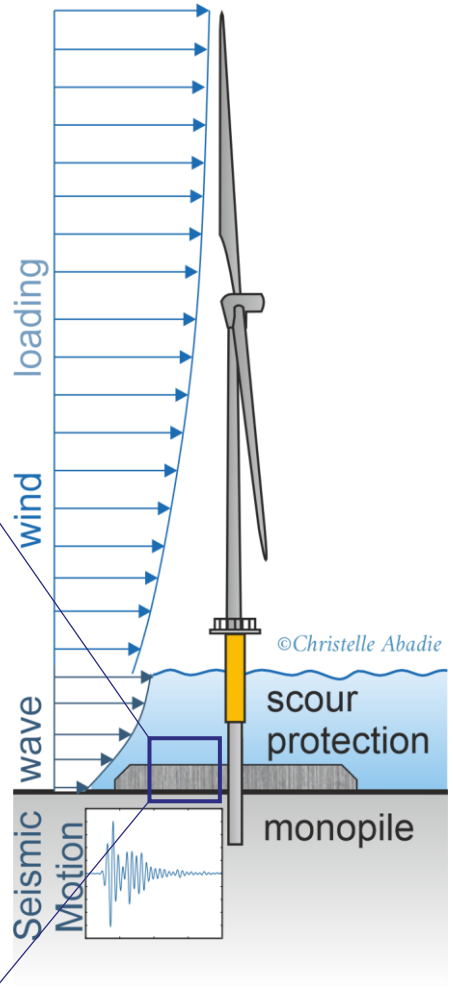
Understand the behaviour of the foundation and scour protection to Earthquake loads
(centrifuge modelling, numerical modelling)

➢ *Expansion to East Asia and America*

New Site Locations







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HR Wallingford
Working with water

- Xu, D., Abadie, C.N., Madabhushi, G., Harris, J., & Whitehouse, R. (2023) – Response of armour rock-scour protection to earthquake-induced liquefaction for offshore wind applications
- **2023 Cooling Prize** - Diarmid Xu
  Rock-scour protection of offshore foundations subjected to earthquake-induced liquefaction

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Progress to date

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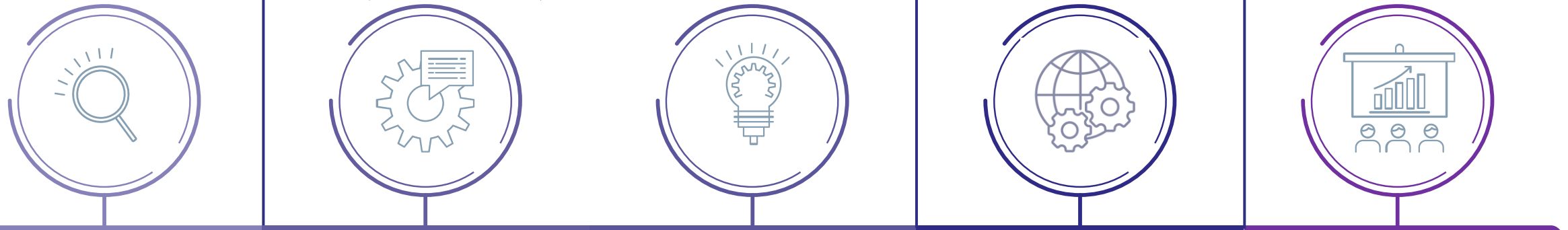
➢ *Subsidy-free offshore wind (bottom-fixed)*

➢ *Expansion to East Asia and America*

➢ *Floating Offshore Wind Demonstrators Conclusive*



Establish Monopile Design Method	Monopile Design Optimisation	Gravity, Jacket Piles & Caissons	New Site Locations	Floating Wind Anchors
≈ early 2000s - 2017	≈ 2010s – Today	≈ 2010s - Today	≈ 2018 – 2030?	Today Onwards
Enable commercial viability of offshore wind in Northern Europe waters	Improve design robustness and installation methods	Provide a wider foundation mix to adapt to large range of offshore environnements	Extend design methods to rest of the world, with different soil conditions and geological hazards	Expand to deeper water depths

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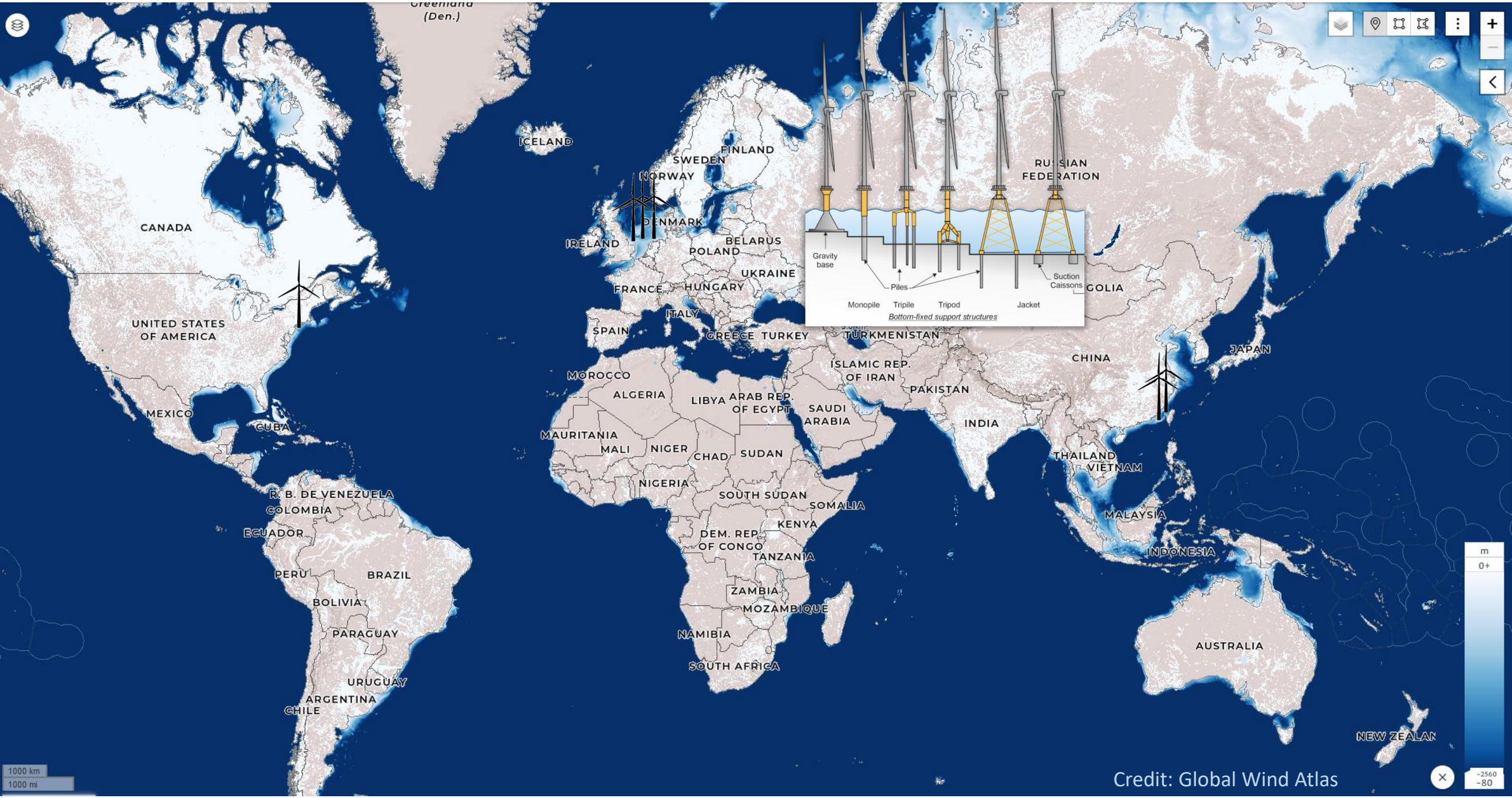
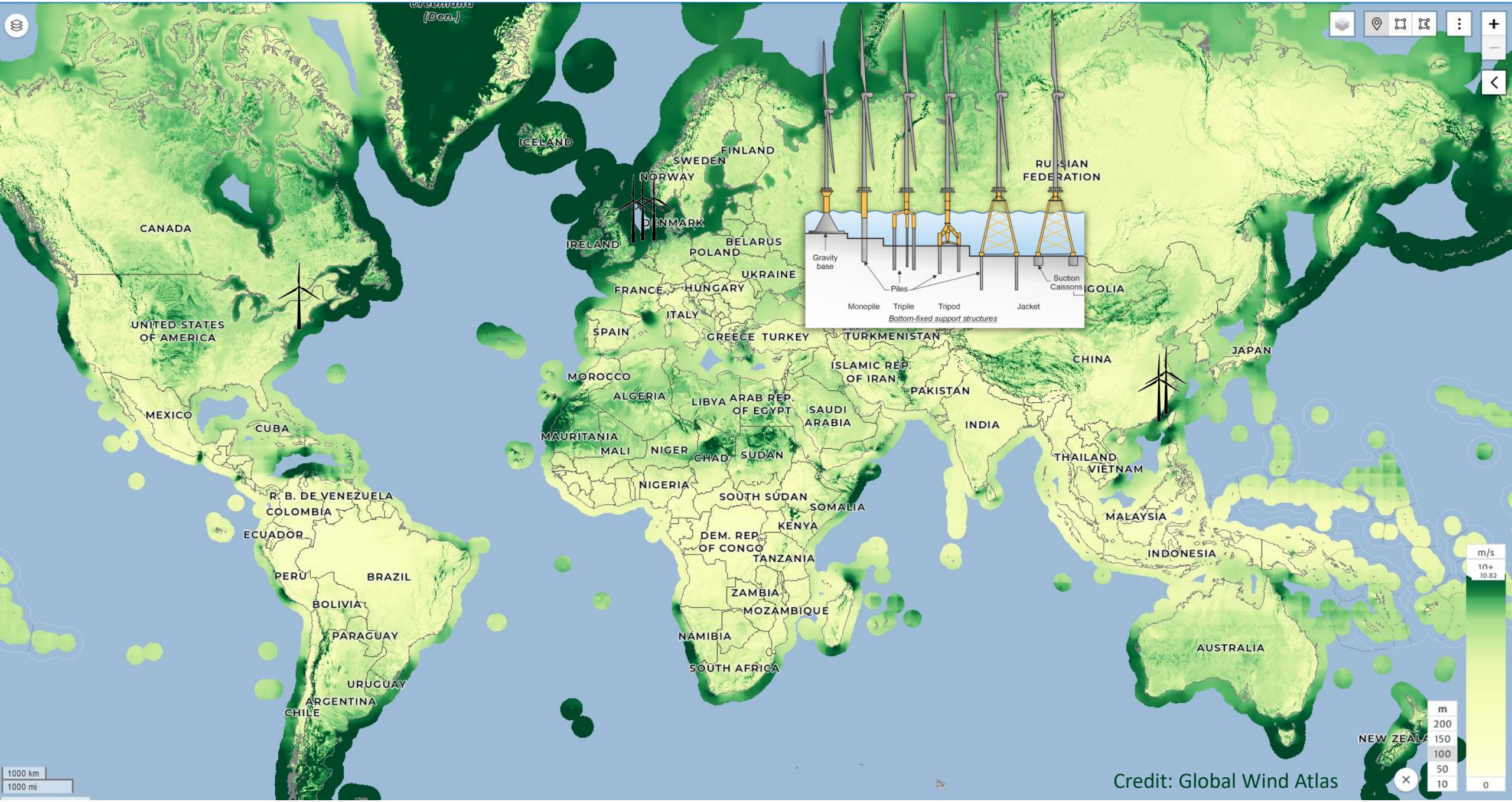
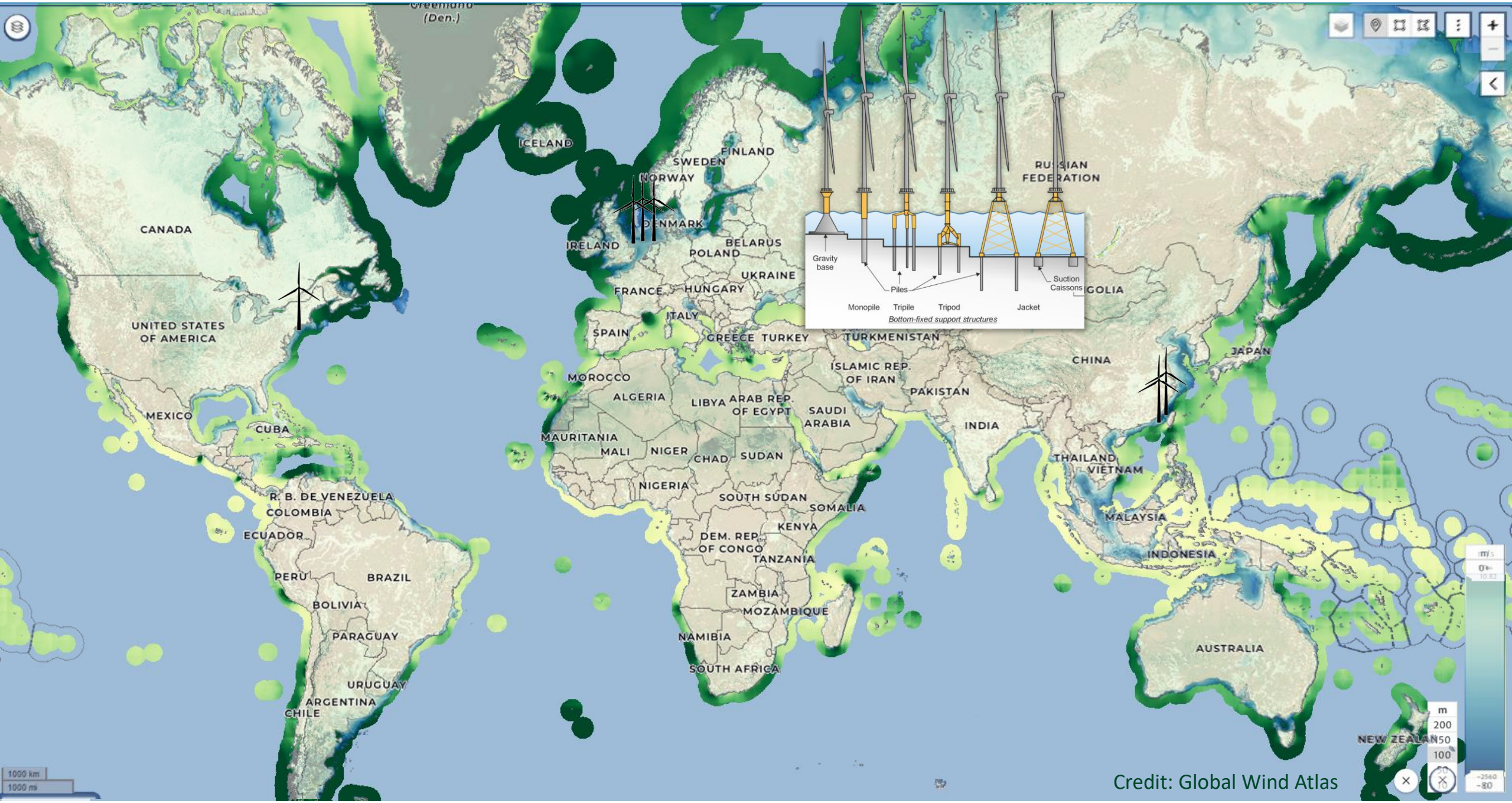


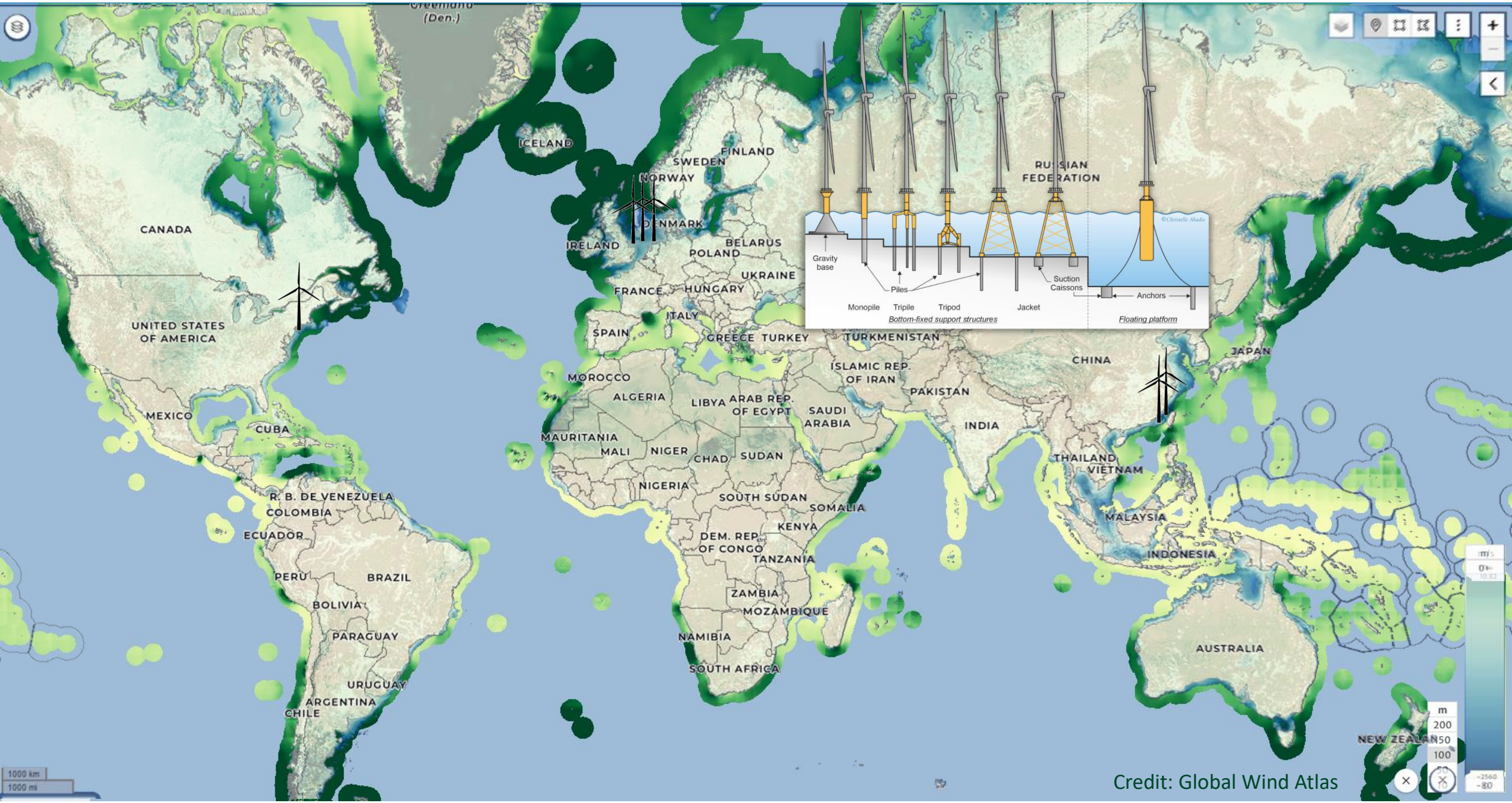
Credit: Global Wind Atlas



Credit: Global Wind Atlas



Credit: Global Wind Atlas



Credit: Global Wind Atlas

Research to support offshore wind

Anchors for Floating Offshore Wind

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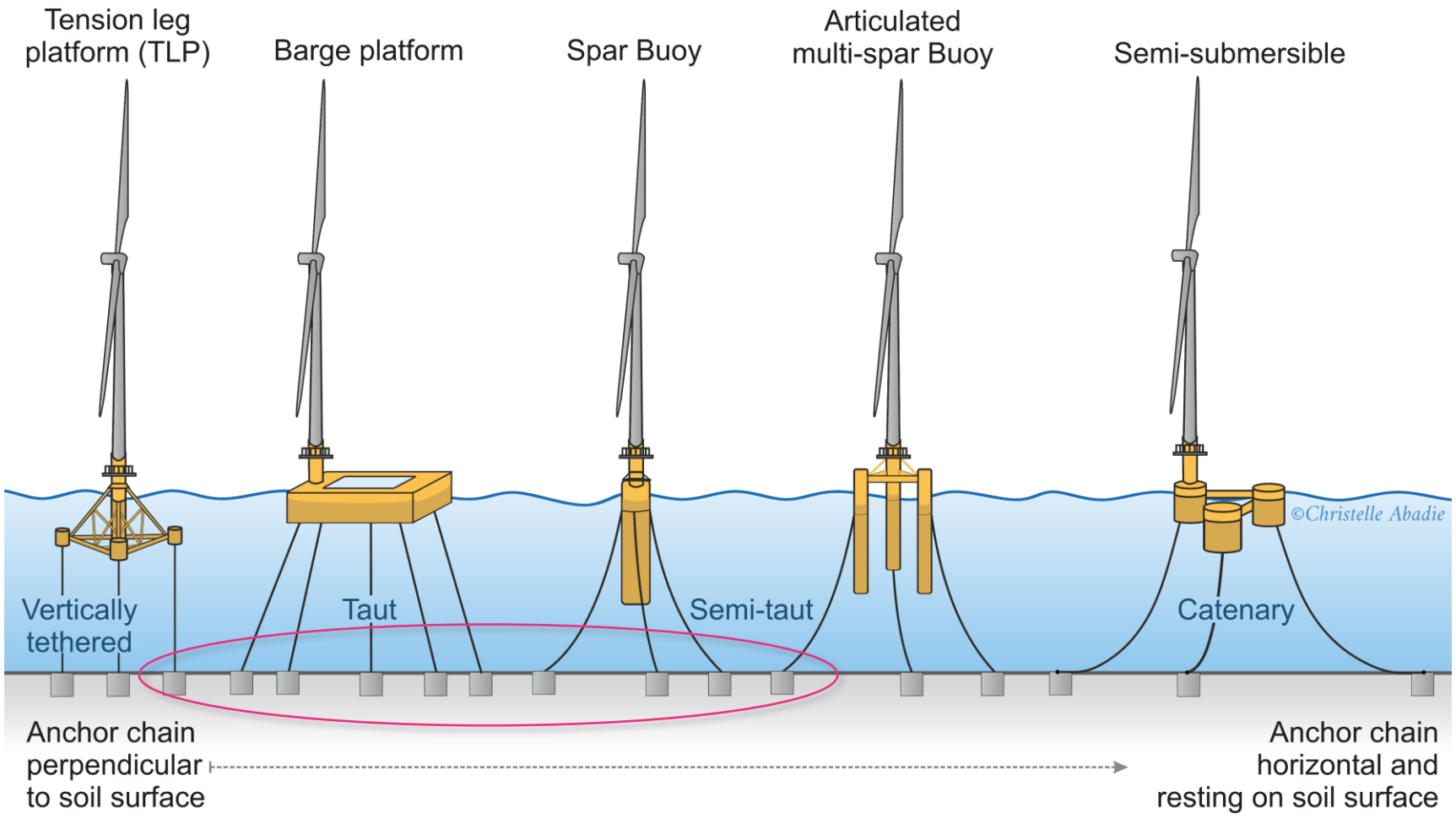

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Anchors for Floating Offshore Wind

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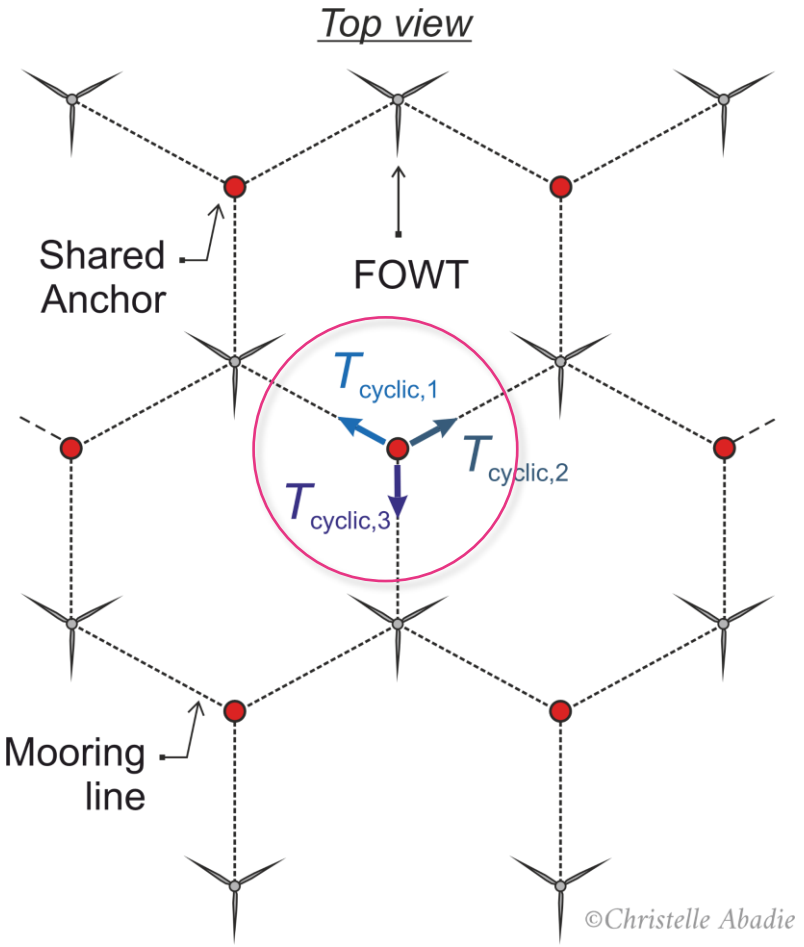

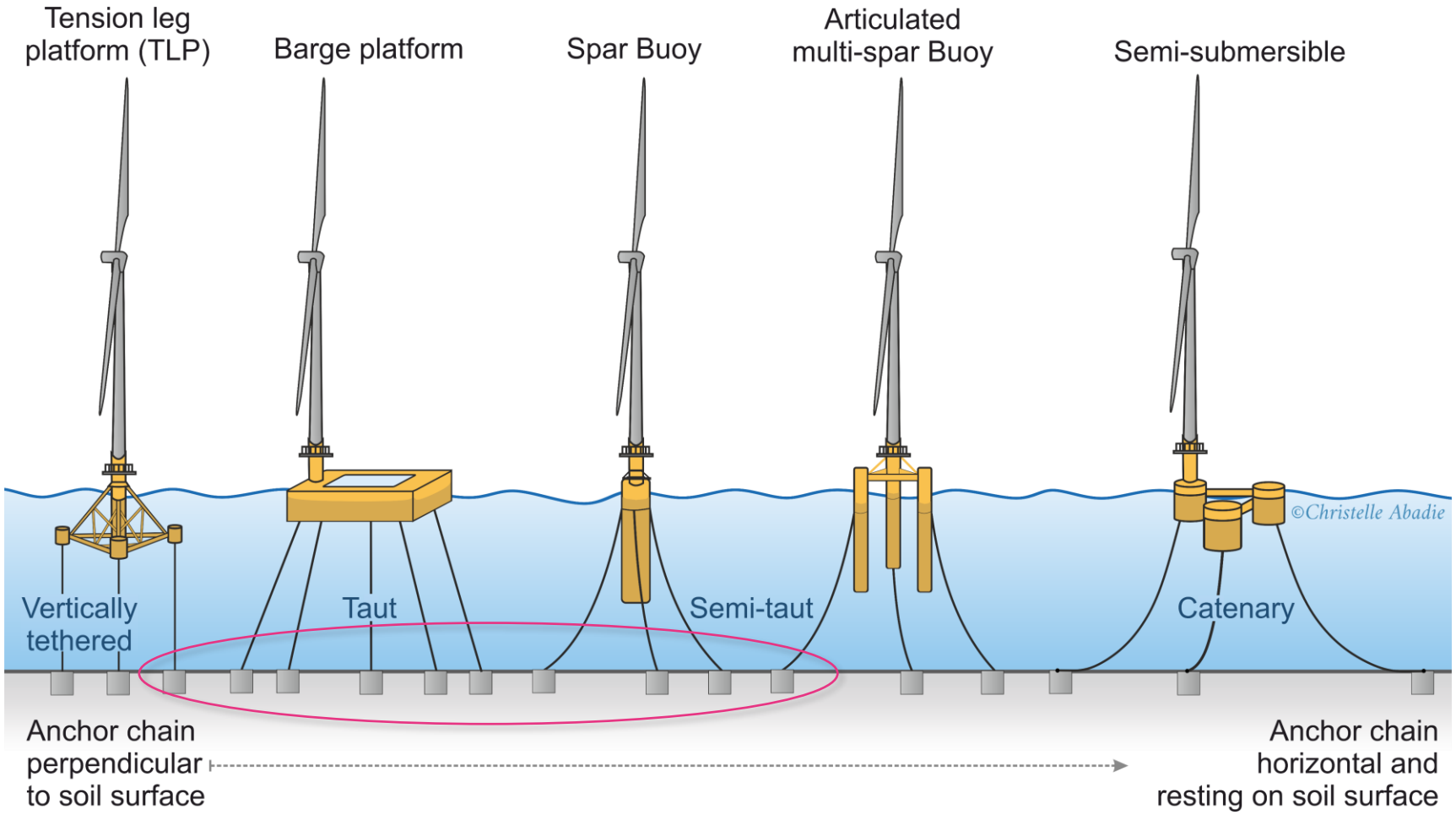

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Anchors for Floating Offshore Wind

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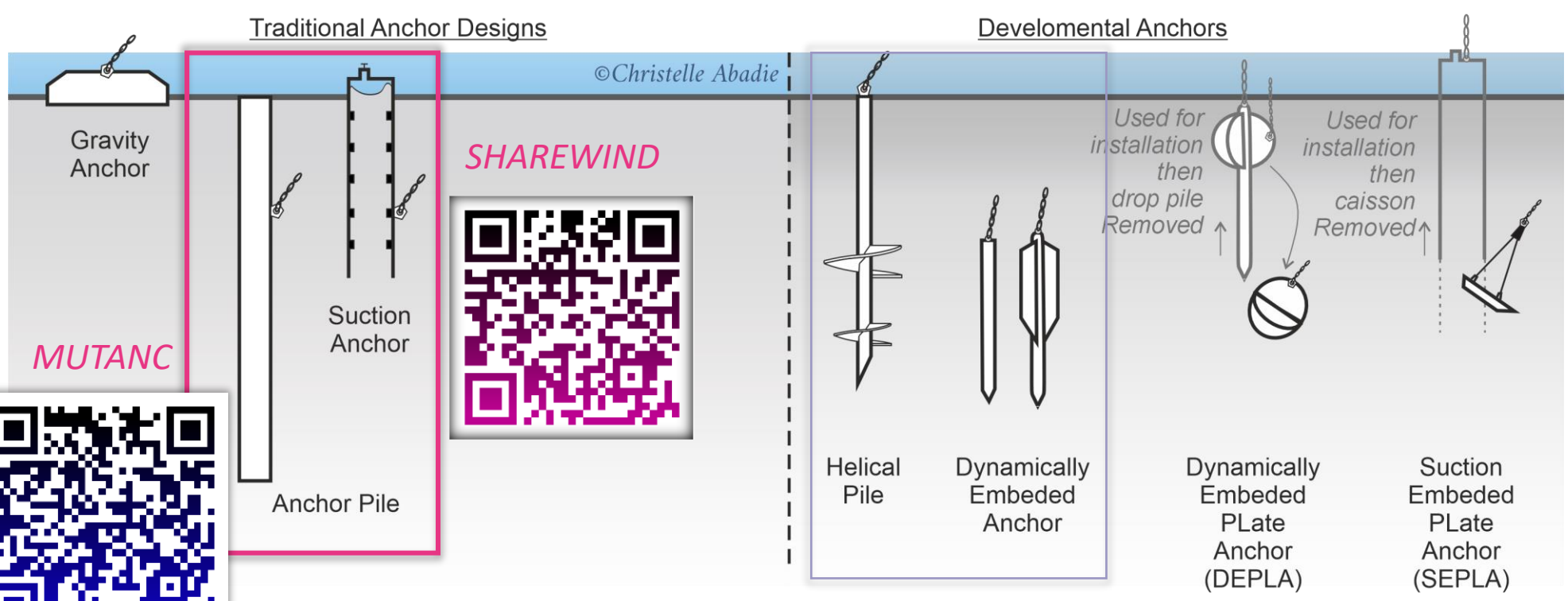

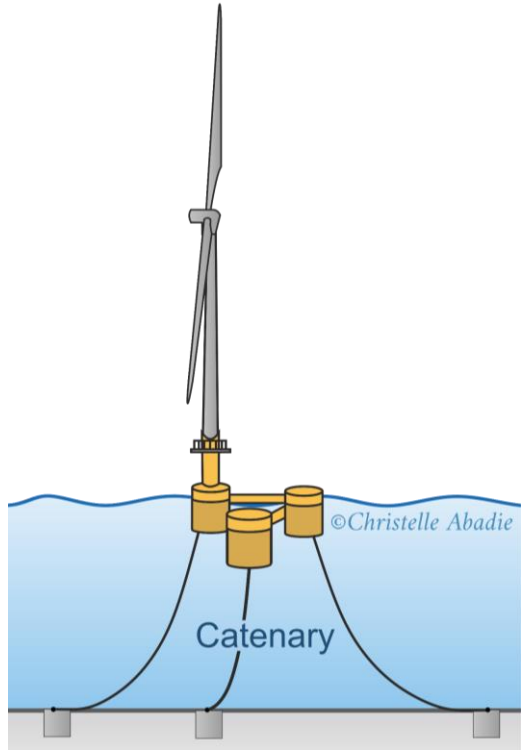

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Anchors for Floating Offshore Wind

Ancres mutualisées pour les éoliennes offshores flottantes

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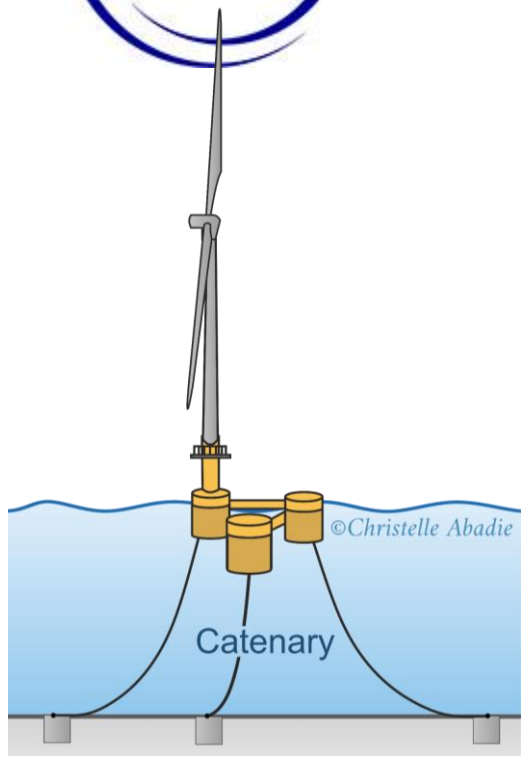
FRANCE 2030



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ISSMGE Interactive Technical Talk:
TC209 – Geotechnics for Offshore Wind

28 February 2024

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FRANCE ENERGIES MARINES

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The MUTANC Project

Objective: Explore the viability of shared anchors as a means to lower the levelized cost of energy for floating offshore wind farms

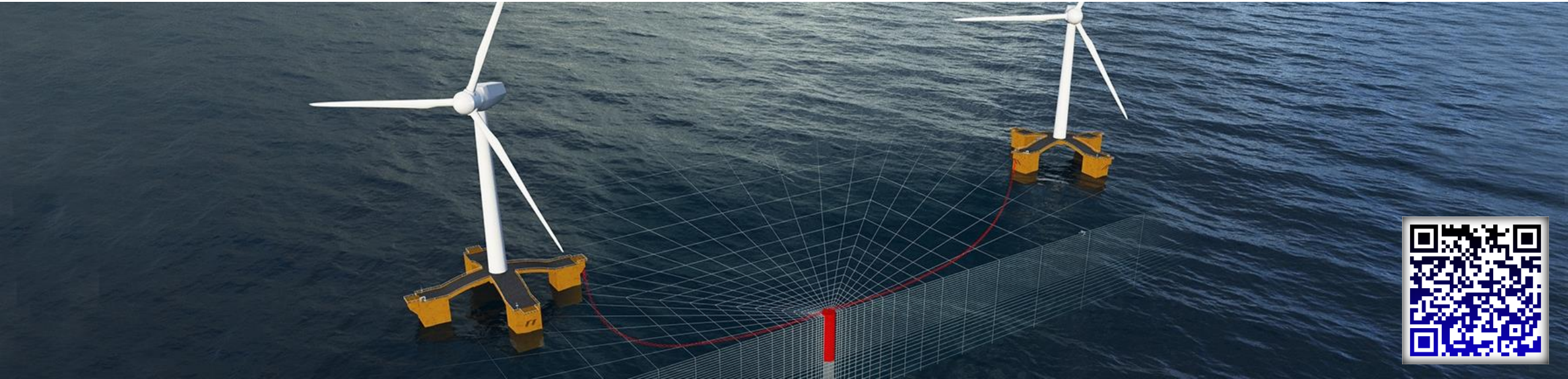
Scientific and technical content

WP1 - Mooring system design and shared anchor load analysis

WP2 - Geotechnical modelling with 3D finite element numerical method

WP3 - Centrifuge tests on small-scale models to study multidirectional loadings and cyclic loadings

WP4 - Cost estimation of mooring systems through experts consultation and existing cost models



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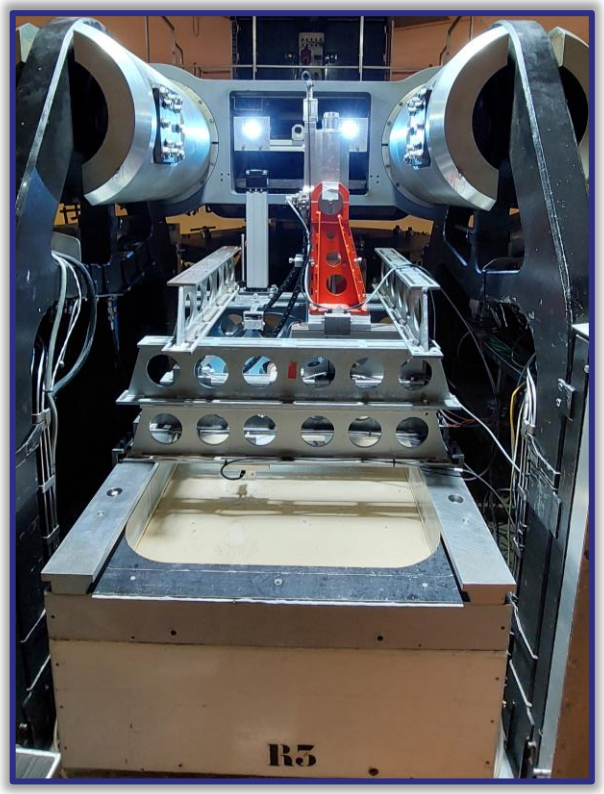
Anchors for Floating Offshore Wind

- Testing of small-scale physical models in the enhanced gravity field of a geotechnical centrifuge
- Prototype stresses and strains are recreated in the models
- Representative multi-directional cyclic loading can be applied via a set of actuators



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Zabatta, R., Abadie, C.N., Blanc, M. and Coquio, T. (2024)
Centrifuge modelling of anchor piles under multi-directional loading for floating wind turbines
5th European Conference on Physical Modelling in Geotechnics (ECPMG 2024)

Research to support offshore wind

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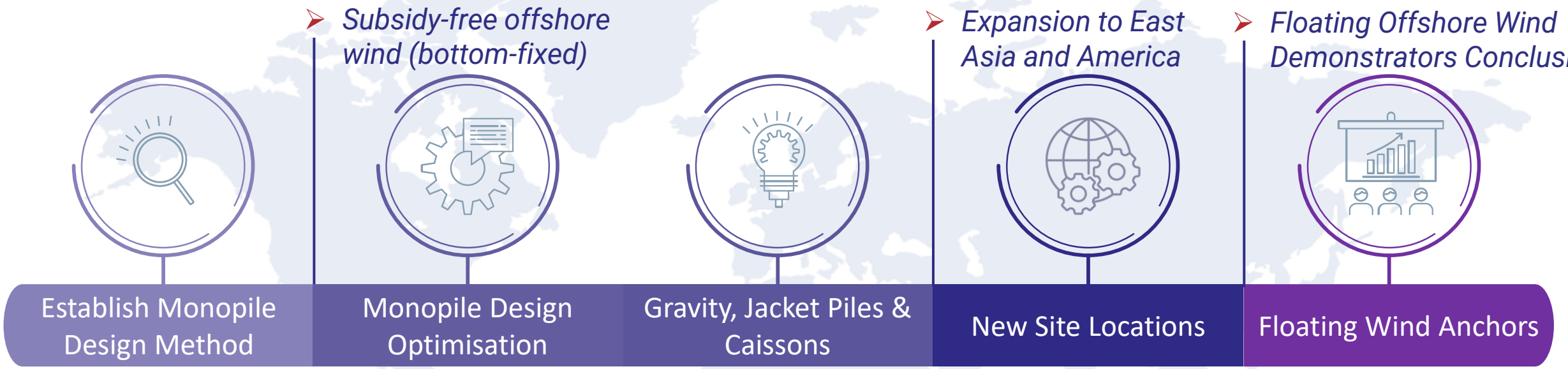
Thank you for listening



➢ *Subsidy-free offshore wind (bottom-fixed)*

➢ *Expansion to East Asia and America*

➢ *Floating Offshore Wind Demonstrators Conclusive*

≈ early 2000s - 2017	≈ 2010s – Today	≈ 2010s - Today	≈ 2018 – 2030?	Today Onwards
Enable commercial viability of offshore wind in Northern Europe waters	Improve design robustness and installation methods	Provide a wider foundation mix to adapt to large range of offshore environnements	Extend design methods to rest of the world, with different soil conditions and geological hazards	Expand to deeper water depths

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