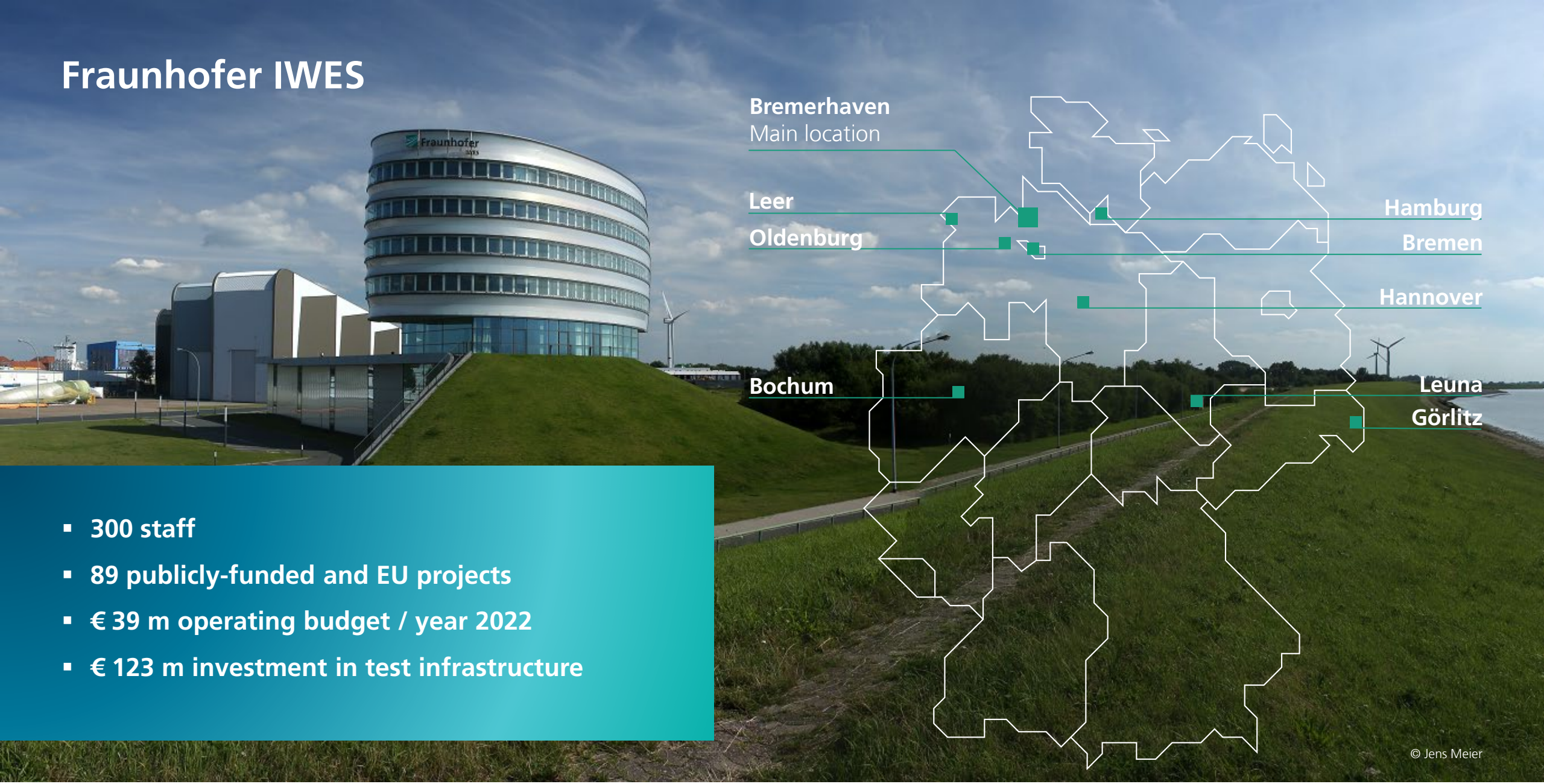
March 13, 2024 / 5th International RAVE Workshop

# Innovative Foundation System for Repowering of Offshore Wind Turbines -InGROW- project

Tulio Quiroz
Fraunhofer Institute for Wind Energy Systems IWES

# Fraunhofer IWES




- 300 staff
- 89 publicly-funded and EU projects
- € 39 m operating budget / year 2022
- € 123 m investment in test infrastructure

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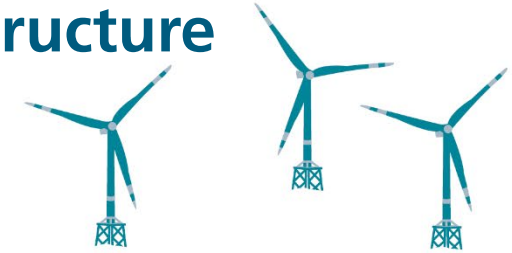
# Our testing infrastructure

2009 – 2024



Assessment of Soil Conditions Bremen

2009

70 m Rotor Blade Hall

1st Lidar Measuring Buoy Bremerhaven

2011 – 2012 – 2013

90 m Rotor Blade Hall Bremerhaven

Engineering Building

Test Center Support Structures Hannover

2014

DyNaLab Bremerhaven

2015

Application Center for Field Measurements Bremerhaven

BladeMaker Bremerhaven

2016

Research Windturbine Bremerhaven

2017

Large Bearing Laboratory Hamburg

2019

Application Center for Integration of Local Energy Systems Hamburg

HiL-GridCoP Bremerhaven

2020

Hydrogen Lab Leuna

2021

Hydrogen Lab Bremerhaven

2023

115 m+ Rotor Blade Test Rig Bremerhaven



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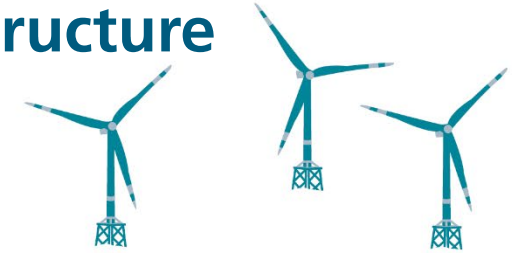

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Hydrogen Lab Leuna

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Hydrogen Lab Bremerhaven

2023

115 m+ Rotor Blade Test Rig Bremerhaven



 

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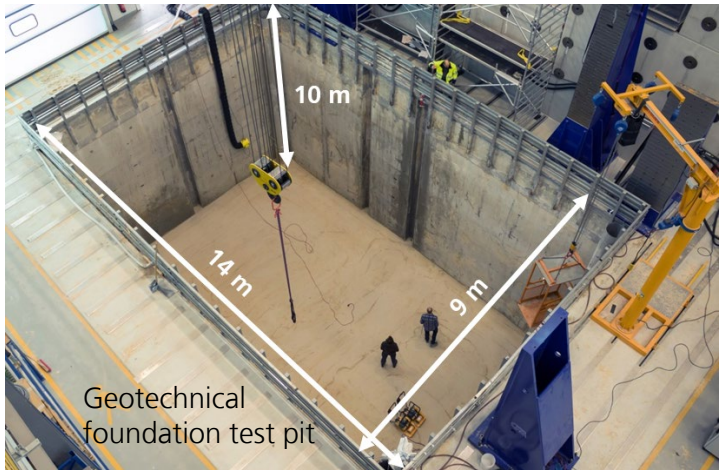
# Department Support Structures

## Optimization of On- and Offshore Support Structures in a Unique Facility


Test Center Support Structures Hannover (TTH)

Strong floor: Horizontal 18,5 x 9,5 m (L x B); Vertical: 9,5 x 10 x 8 m (L x B x h)




Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Niedersachsen

Leibniz Universität Hannover

European Union
European Regional Development Fund

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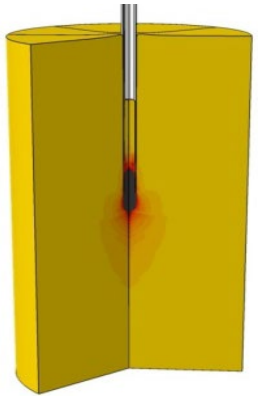
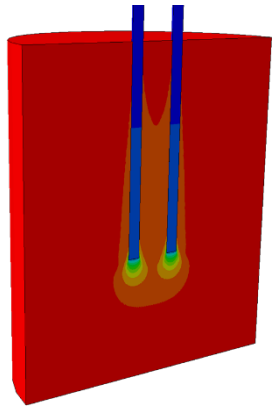
# Our Competences

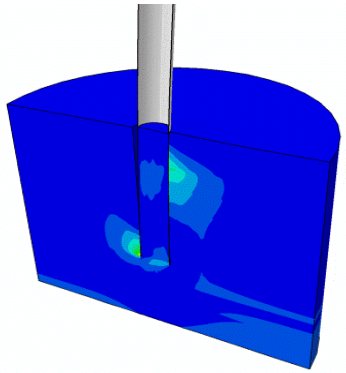
## Development and Validation of Design Methods and Installation Techniques



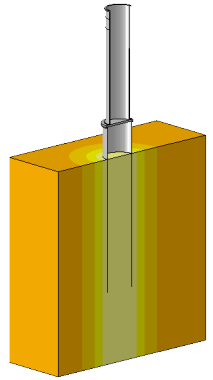
Axial loaded pile



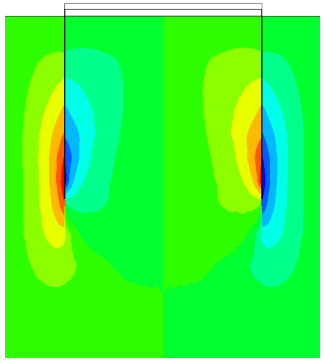
Pile groups



Lateral loaded piles



Installation effects



Suction Buckets

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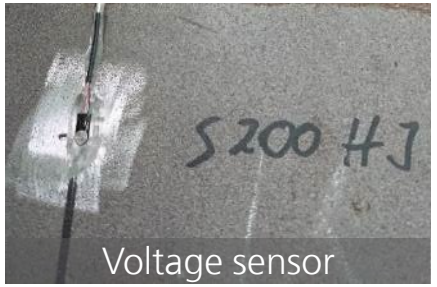
# Fraunhofer IWES - Department Support Structures

## Monitoring concept

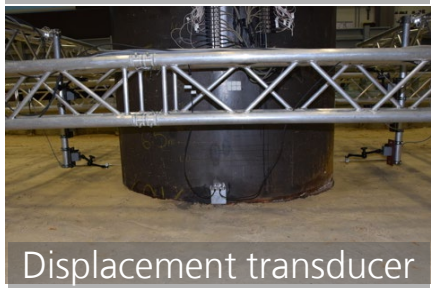
Pile installation- left: Driven pile
right: vibrated pile

Load test








Instrumentation in the pile and soil

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# Research project InGROW (FKZ 03EE003, 2019-2022)

## **I**nnovatives **G**ründungssystem für das **R**epowering von **O**ffshore-**W**indenergieanlagen

Innovative foundation system for repowering of offshore wind turbines

### Research subject

- Reutilization of existing locations and infrastructure for repowering
- Monopile foundations for offshore wind turbines
- Typical soil conditions of the German North Sea
- Early repowering with significant increase in turbine power

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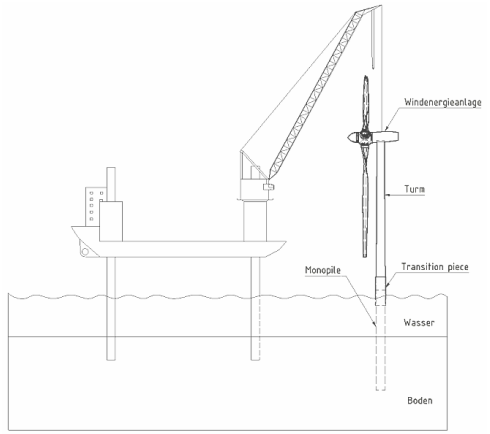
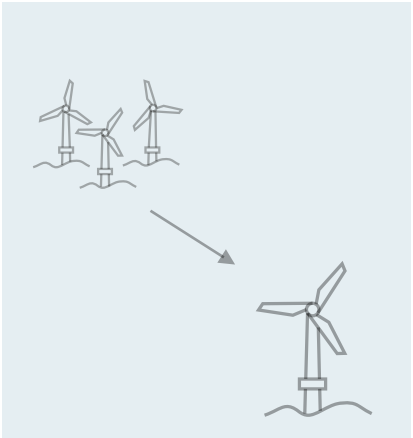
ptj Projektträger Jülich Forschungszentrum Jülich

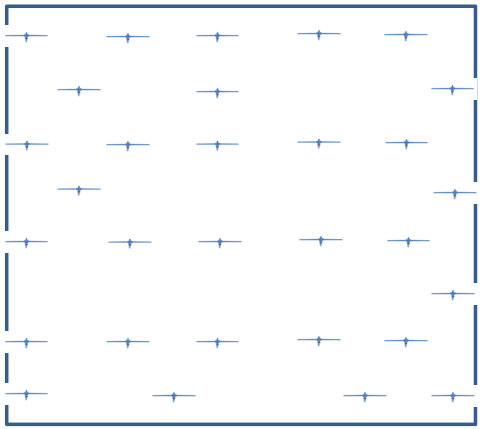
Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag





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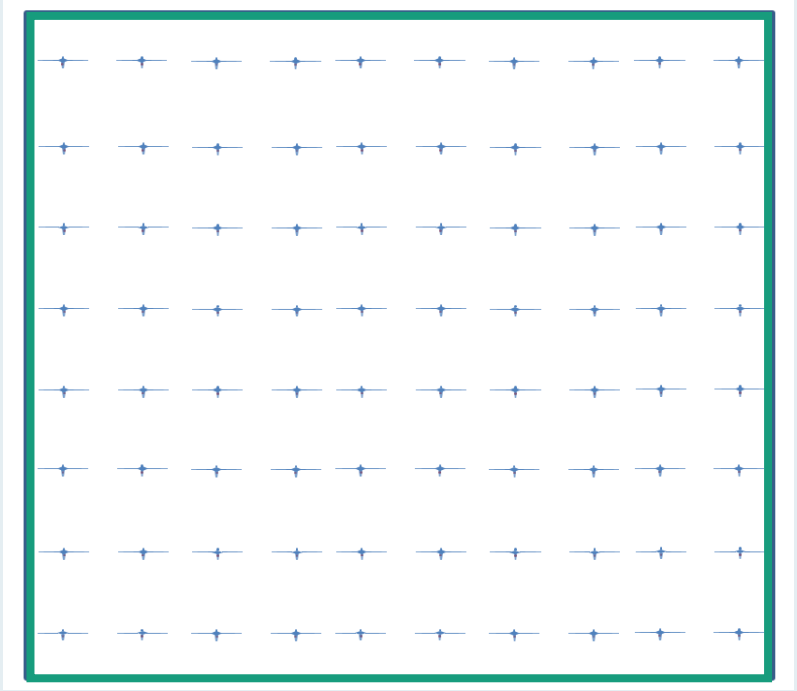
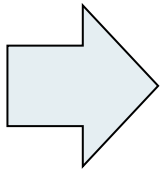
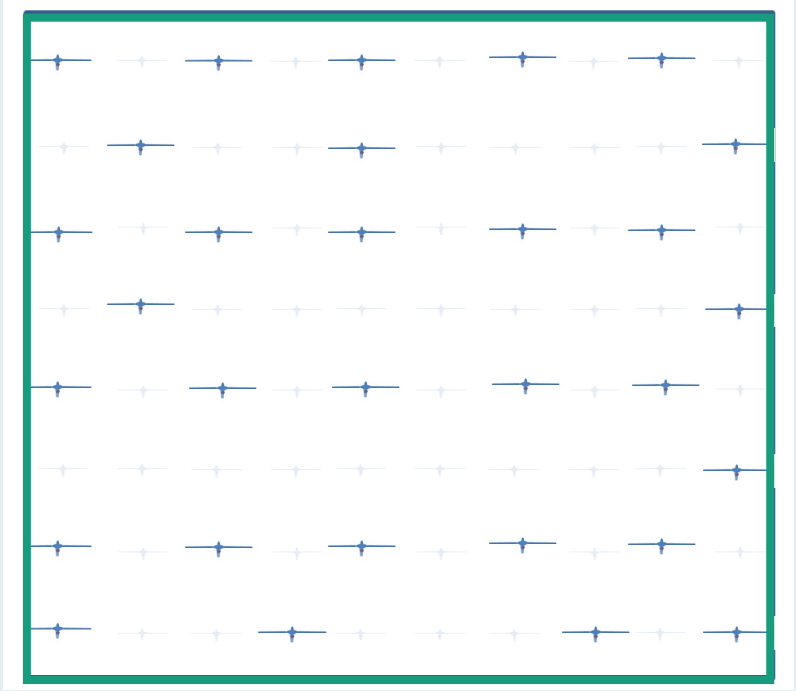
# Exemplary wind farm layout after offshore repowering

## Reduction of number of turbines and reutilization of existing electrical 33 kV infrastructure



**n = 80, @ 3,6 MW/OWT**
**Nominal output: 288 MW**
**Existing wind farm layout**

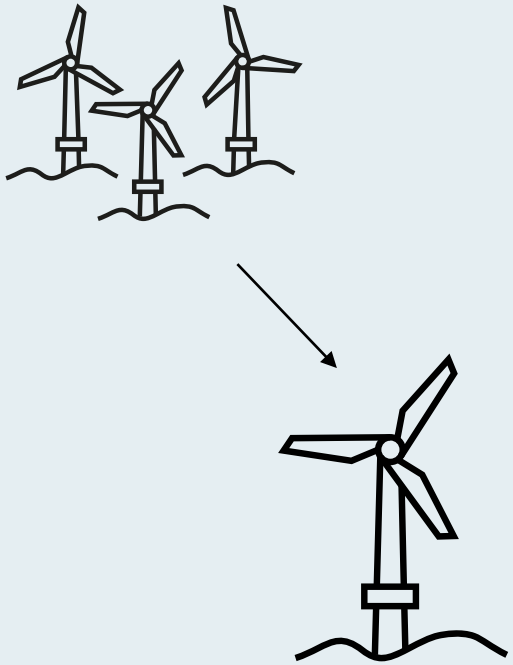




**n = 31, @ 9,5 MW/OWT**
**Nominal output: 295 MW**
**Wind farm layout after repowering**

# Benefits of early repowering

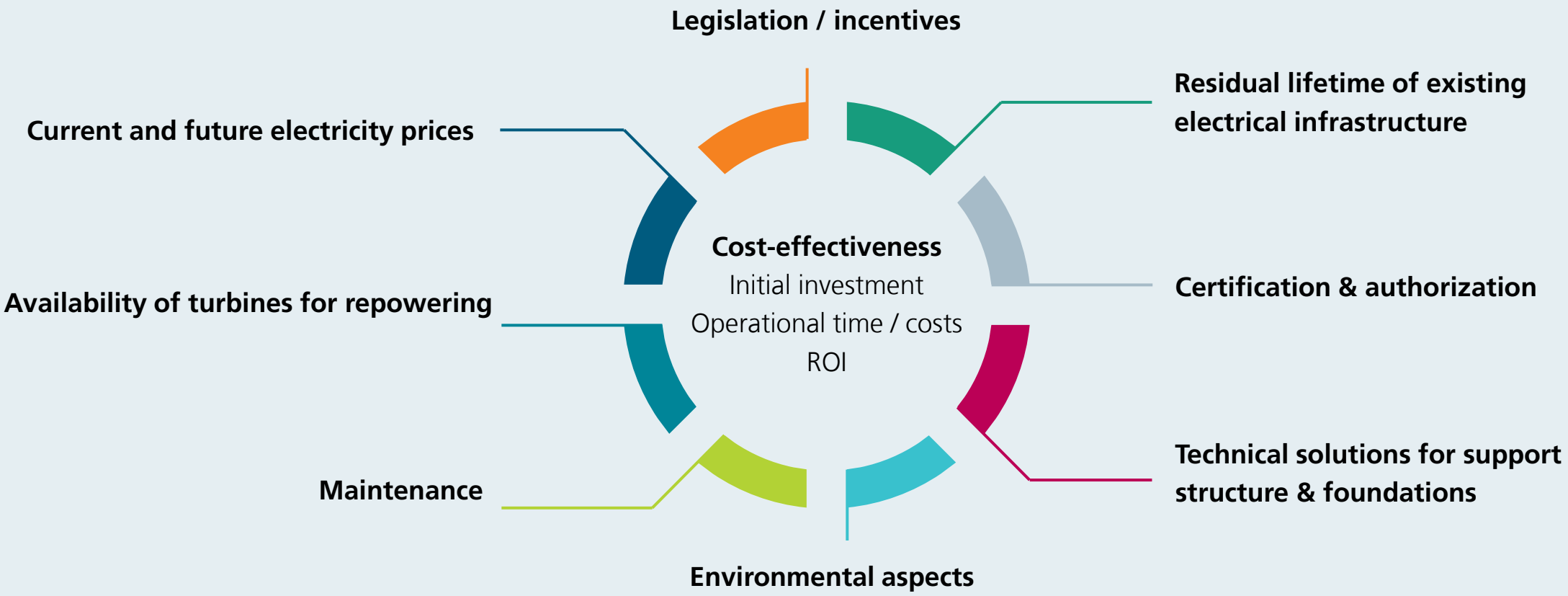
- Energy **efficiency**, less turbines by equivalent power output
- Less **maintenance** due to reduced number of turbines after repowering
- Possibility of **reutilization of exiting sites**, meteorological and geological data
- **Reduction of downtime** in power generation in comparison with conventional full decommissioning for new wind farm scenario
- By replacing with very powerful wind turbines, **possibility of green hydrogen production** and storage
- Possibility of further **utilization of existing scour protection**
- **Reutilization of existing foundations** (where possible) **through strengthening** thinkable



$(MW)_{old} < (MW)_{new}$

# Developing a sustainability business case for offshore repowering

## Factors that influence the decision-making process



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# Developing a sustainability business case for offshore repowering

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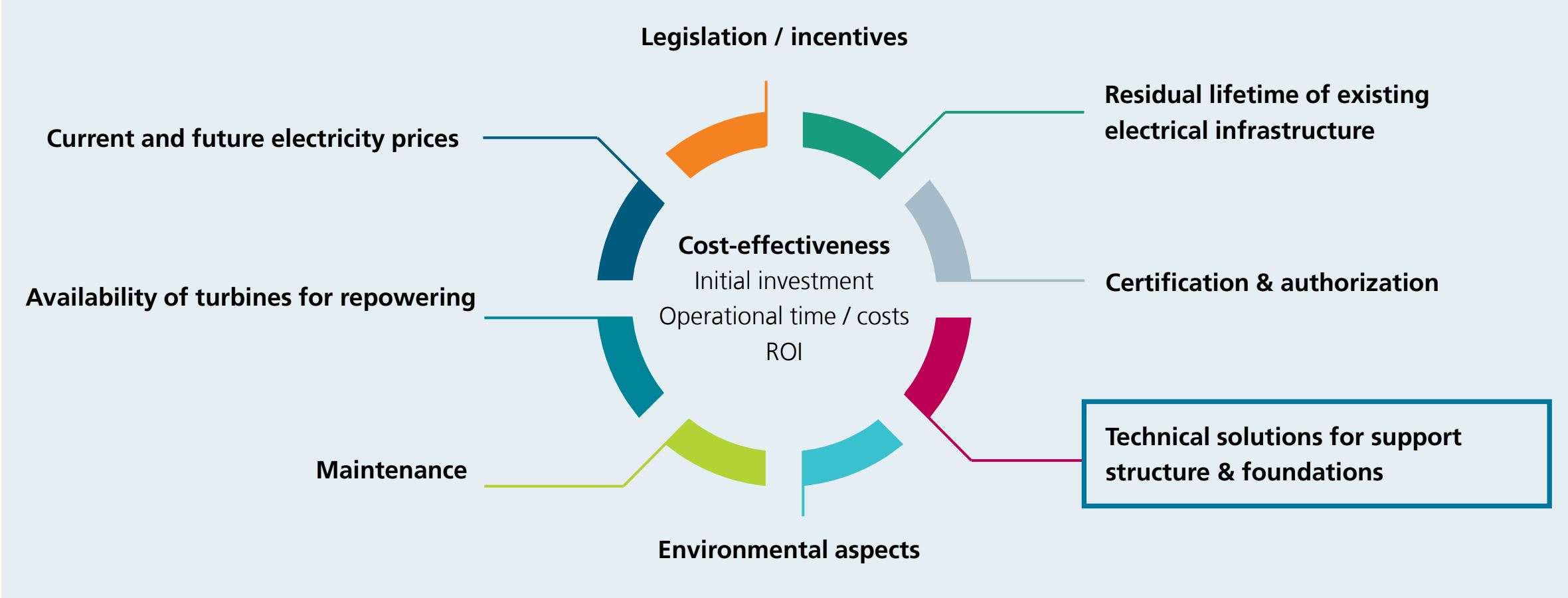


 

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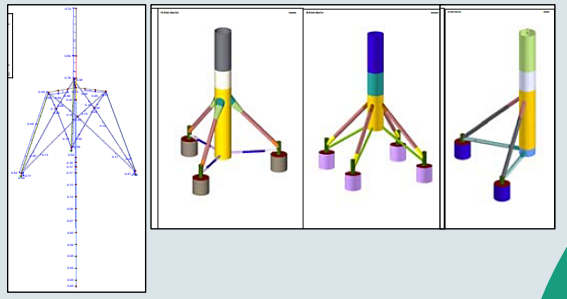
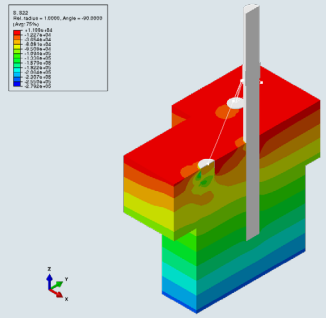
# InGROW project

## Work packages



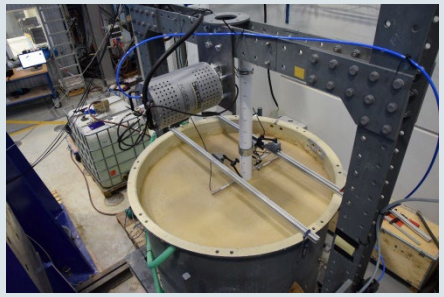
**WP 1**

Concepts and design study: foundation system for repowering



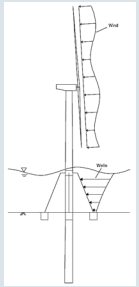
**WP 2**

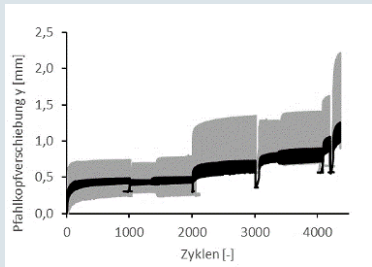
Numerical simulation of load-bearing behaviour



**WP 3**

Small scale demonstrator






**WP 4**

Preliminary design concept and overall assessment

# Concepts and design study

## Definition of a generic reference situation for the design of support structure

### Fictive conditions assumed for preliminary design

| | Existing Turbine, before repowering | After Repowering |
|---|---|---|
| **Turbine power [MW]** | 5 | 10 |
| **Water depth [m]** | 26 | |
| **Load cases considered** | | Calculated for the structures on the basis of INNWIND.EU project |
| **Maximum degree of utilisation assumed at pile mudline level (idealisation)** | $D_f$ = 75% | $D_f$ = 100% |
| **Wind loads ULS, SLS, FLS at tower level** | | From INNWIND.EU project |
| **Sea loads incorporated** | | Generated with WaveLoad 2 for FINO 1 location |
| **Tower diameter at interface level [m]** | 6 | 7,6 (From INNWIND.EU project) |
| **Tower mass [t]** | 350 | 473 |
| **Sand profile** | Sand | From INNWIND.EU project |

# Concepts and design study

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# InGROW concept

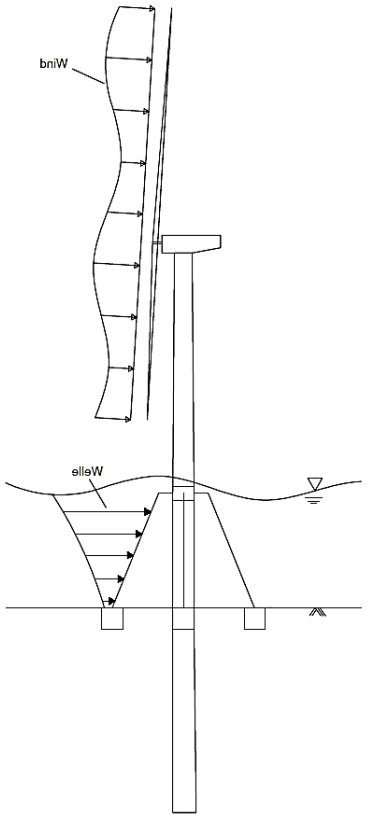
## Strengthening of an existing monopile foundation for early repowering

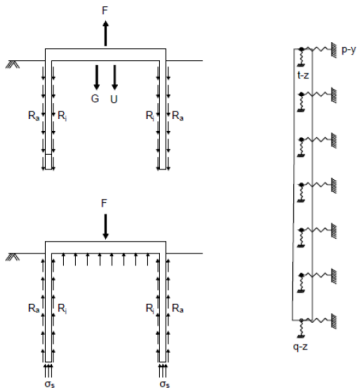
### Integration of a new support structure on suction buckets

- Existing monopile will be upgraded:
  - Steel frame construction
  - Support adapter / central tube
  - Suction buckets as foundation elements
  - Connection between support adapter and existing pile via e.g. grout connection

- Combined load transfer via support structure and existing pile:
  - Relief of the existing pile
  - Increase in the overall rigidity of the system

- Variable arrangement of the foundation strengthening possible





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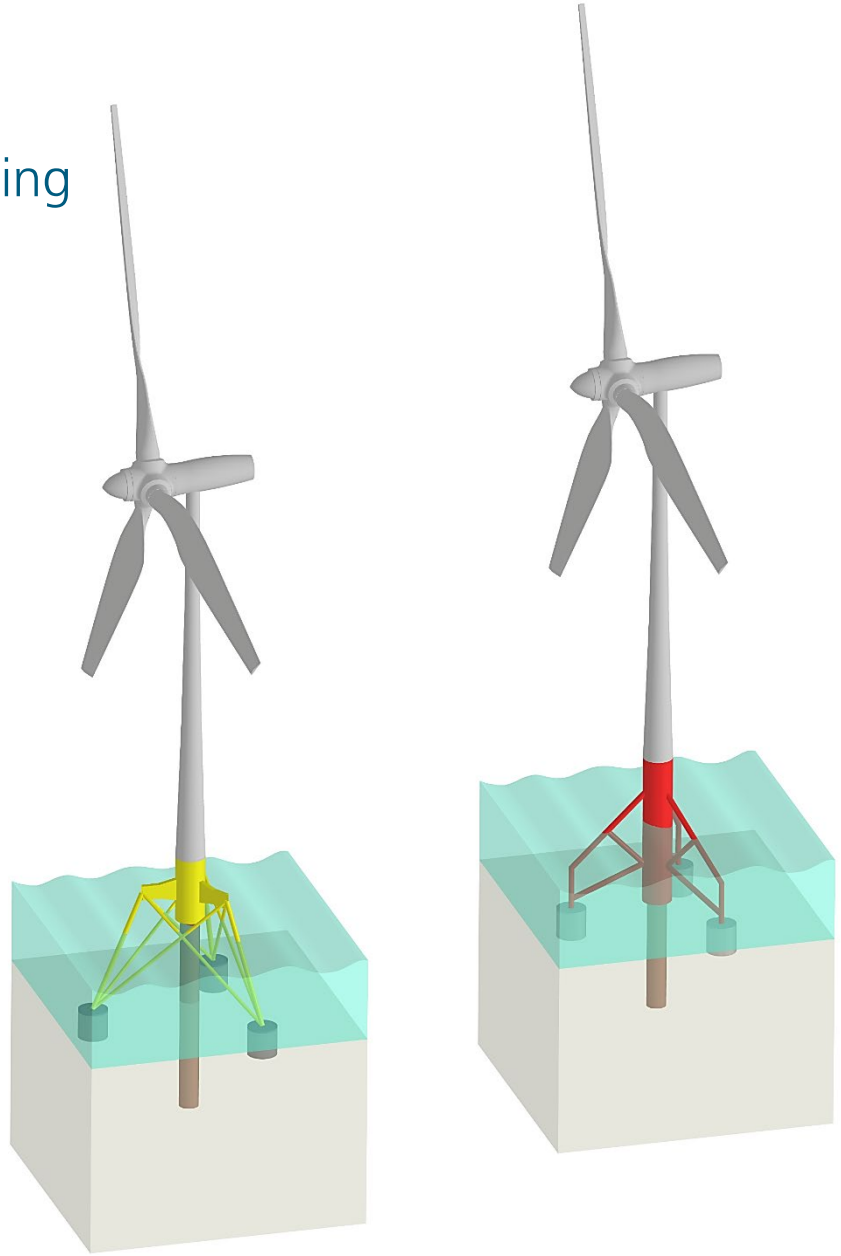


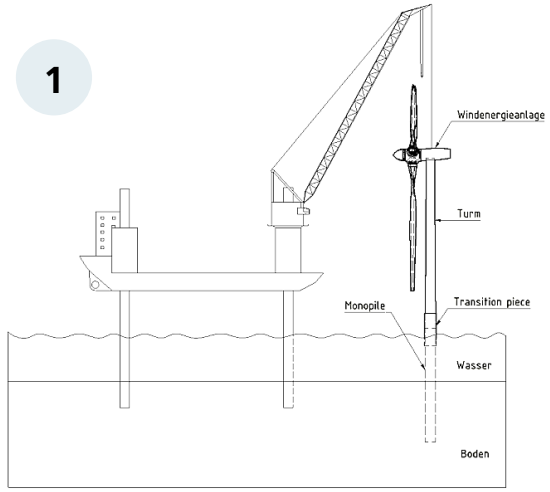
# InGROW concept

## Installation sequence

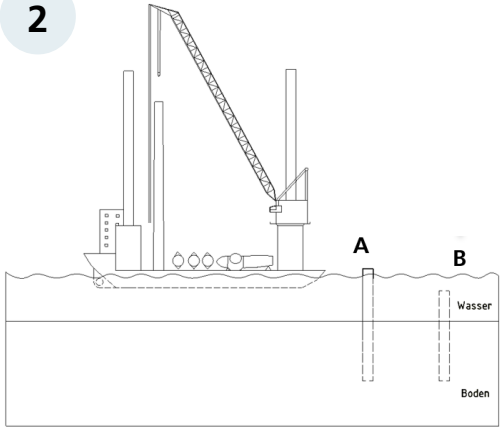
Partial dismantling

**1-2**

**1**




**2**







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# InGROW concept

## Installation sequence

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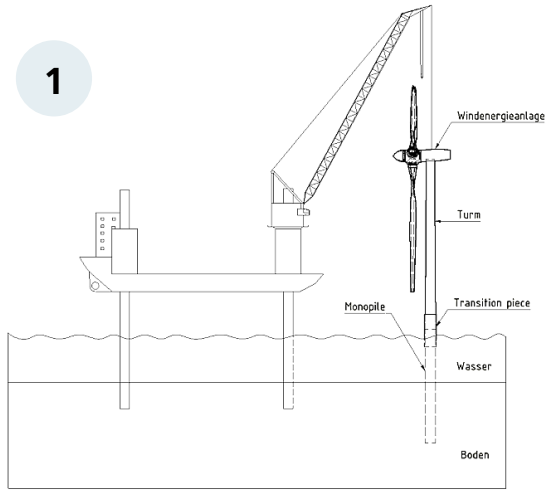


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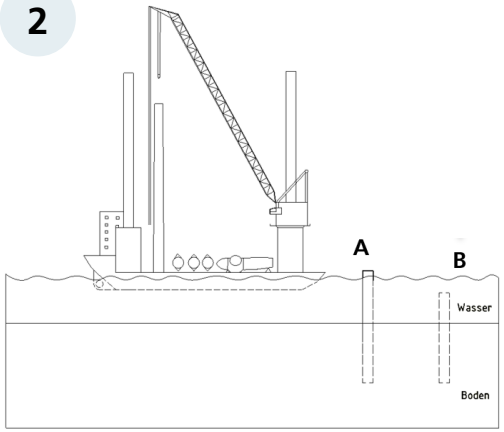


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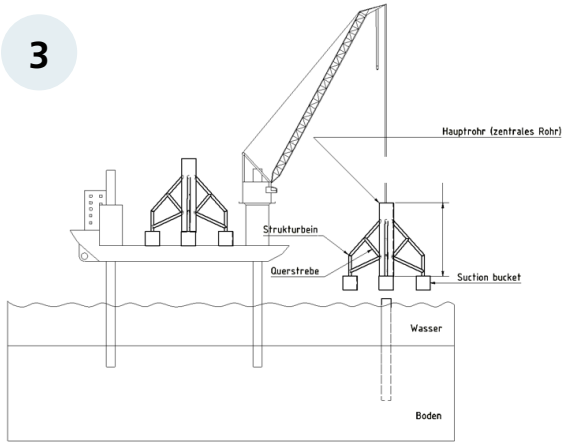


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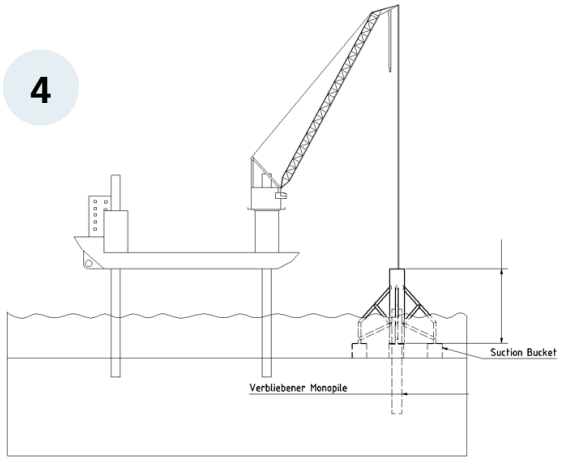


Partial dismantling
**1-2**

Creation of a new foundation reinforcement
**3-5**




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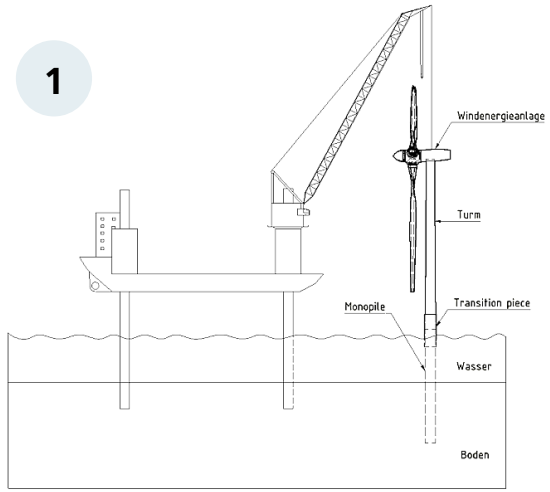
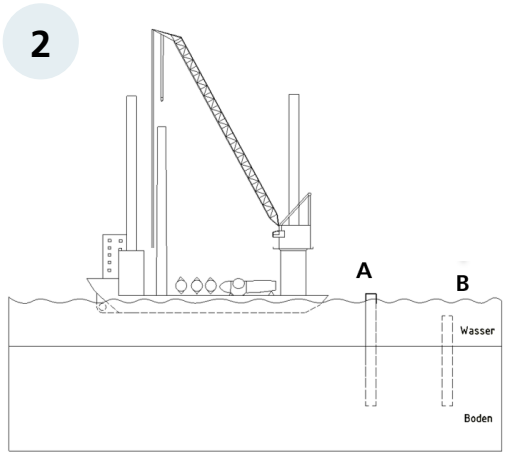
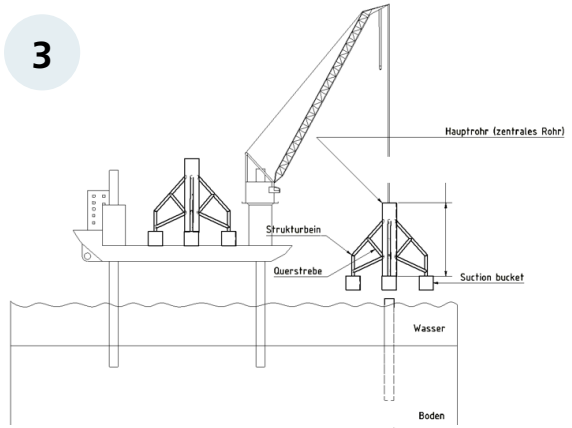
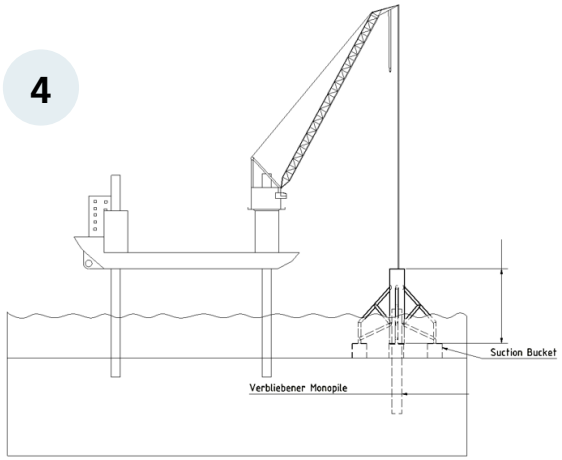
# InGROW concept

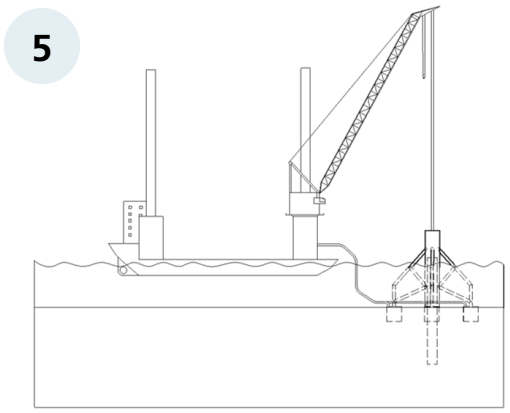
## Installation sequence

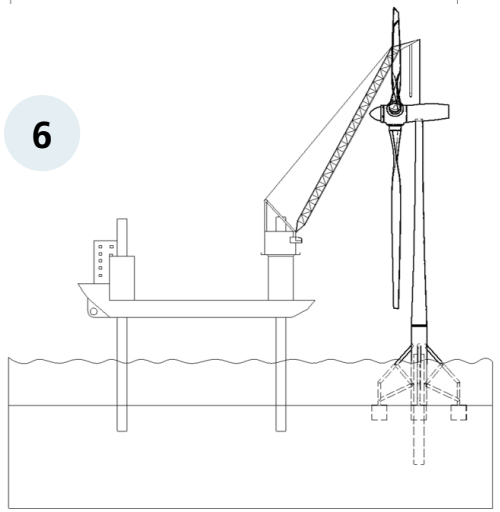


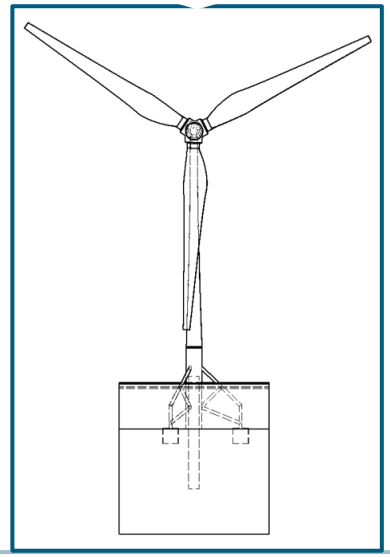




Partial dismantling
**1-2**

Creation of a new foundation reinforcement
**3-5**

Installation of a new powerful WTG
**6**



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# Concepts and design study

## Definition of a generic reference situation for the design of support structure

### Generic repowering scenario for the design study

| | Existing Turbine | After Repowering | |
|---|---|---|---|
| **Turbine power [MW]** | 5 | 10 | |
| **Rotor diameter [m]** | 126 | 178,3 | |
| **Hub height [m]** | 153 | 119 | |
| **Rotor blade length [m]** | 61,5 | 86,37 | |
| **Monopile diameter [m]** | 5,8 | | |
| **Foundation system analysed (excerpt)** | | **Degree of utilisation of monopile ULS-loads [%]** | **New steel required for substructure [t]** |
| **Old monopile D = 5,8 m (568 t)** | | 180 | - |
| **Old monopile D = 5,8 m + InGROW Strengthening** | | 31 | 563 |
| **New monopile D = 6 m, increased wall thickness** | | 85 | 843 |

# Concepts and design study

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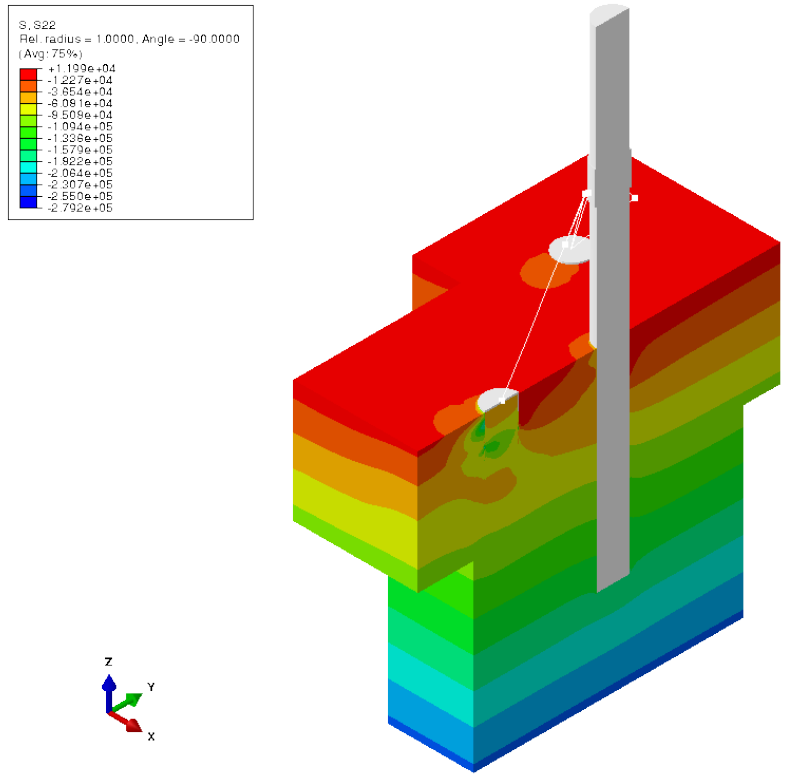
| **Monopile diameter [m]** | 5,8 | | |
| **Foundation system analysed (excerpt)** | | **Degree of utilisation of monopile ULS-loads [%]** | **New steel required for substructure [t]** |
| **Old monopile D = 5,8 m (568 t)** | | 180 | - |
| **Old monopile D = 5,8 m + InGROW Strengthening** | | 31 | 563 |
| **New monopile D = 6 m, increased wall thickness** | | 85 | 843 |

# InGROW concept

## Strengthening of an existing monopile foundation for early repowering

### Integration of a new support structure on suction buckets

- Existing monopile will be upgraded:
  - Steel frame construction
  - Support adapter / central tube
  - Suction buckets as foundation elements
  - Connection between support adapter and existing pile via e.g. grout connection
- Combined load transfer via support structure and existing pile:
  - Relief of the existing pile
  - Increase in the overall rigidity of the system
- Variable arrangement of the foundation strengthening possible




Finite element simulation of equivalent structure

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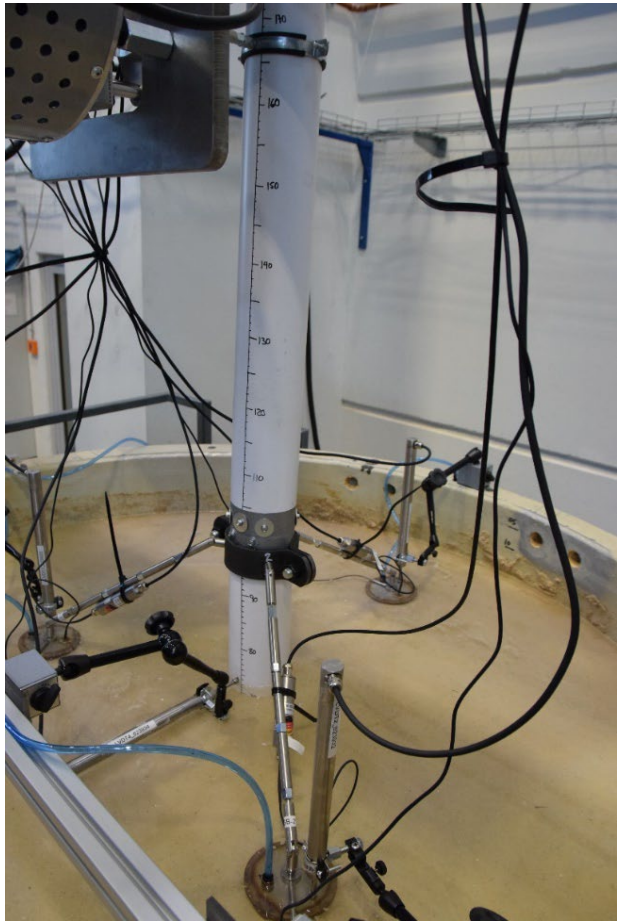

Experimental setup for small-scale investigations

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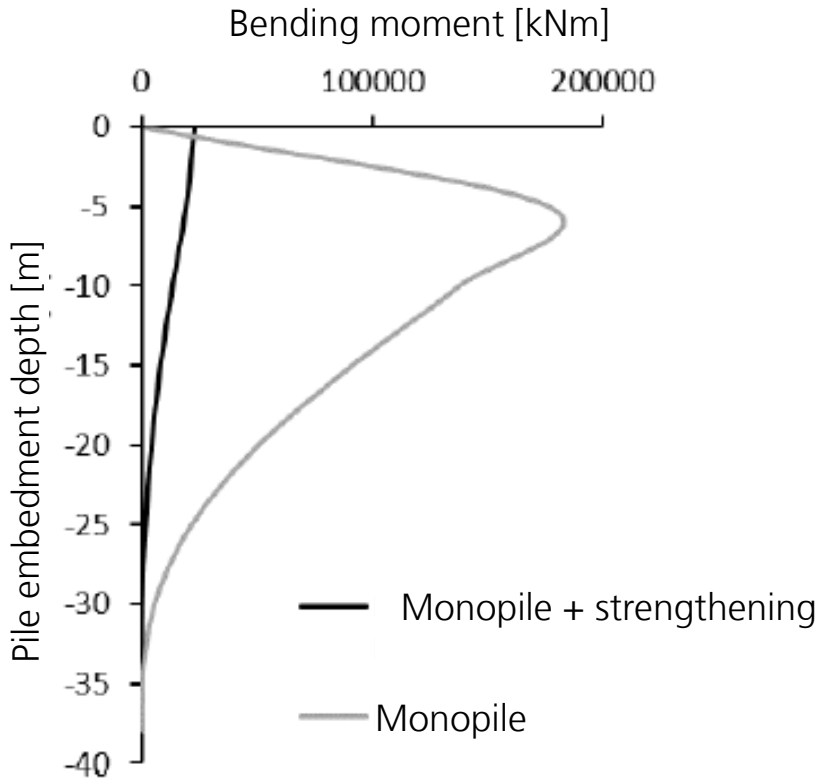


 

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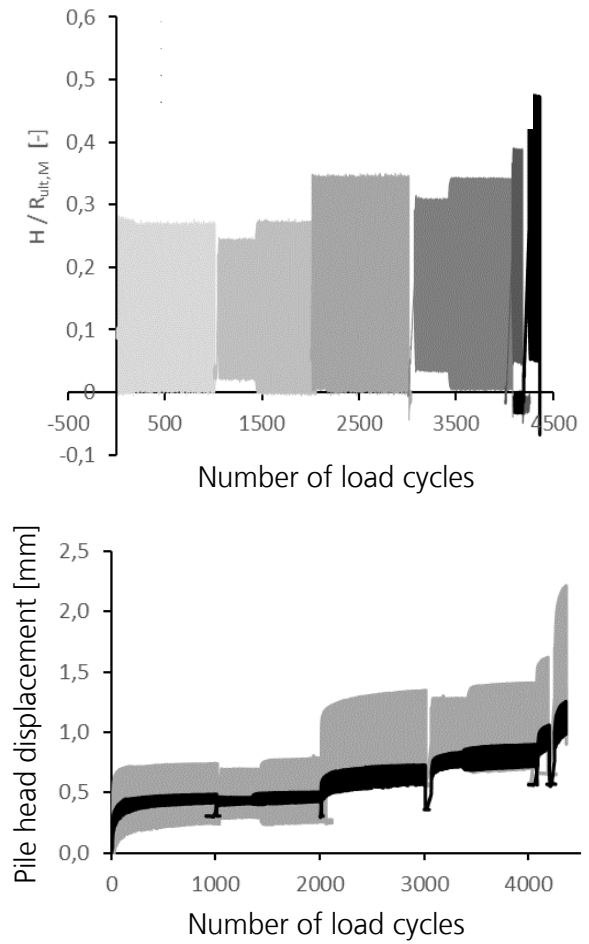


Experimental results from the small-scale tests

 

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# Outlook und future work

## Project results

1. Foundation reinforcement for offshore repowering technically possible
2. Concept developed for upgrading monopiles. Combination of proven tested foundation technologies
3. Basic knowledge of the overall load-bearing behaviour through num. simulations and demonstration tests
4. TRL 3-4 achieved
5. Positive assessment of the basic certifiability of the concept
6. Roadmap for future certification

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## Challenges

1. **Validation** of the design approach using **large-scale** verification tests in a relevant environment
2. Further development of the concept with the **involvement of industry**
3. Clarification of the **regulatory framework** for foundation **strengthening for repowering**
4. Assessment of **economic efficiency** of repowering and re-evaluation with more realistic assumptions

# Thank you for your attention

 

# Contact

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