Comparative Levelized Cost of Energy Analysis

EERA DeepWind 2015

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SWE Stuttgart Wind Energy

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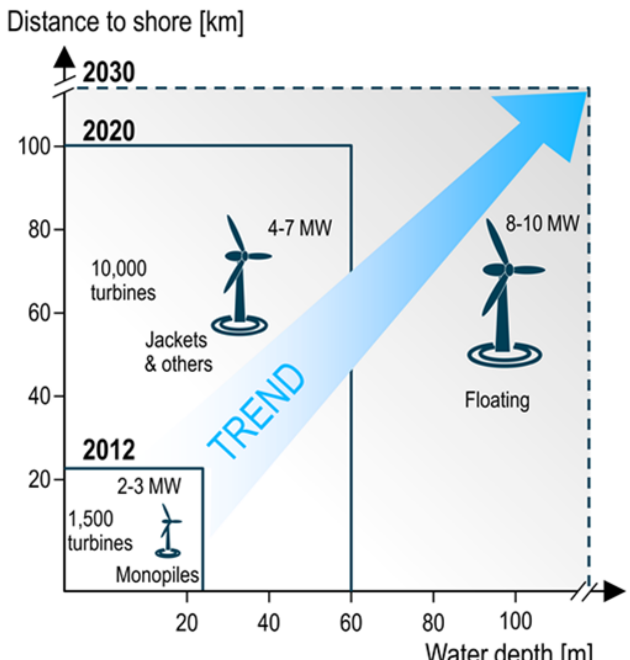
Content

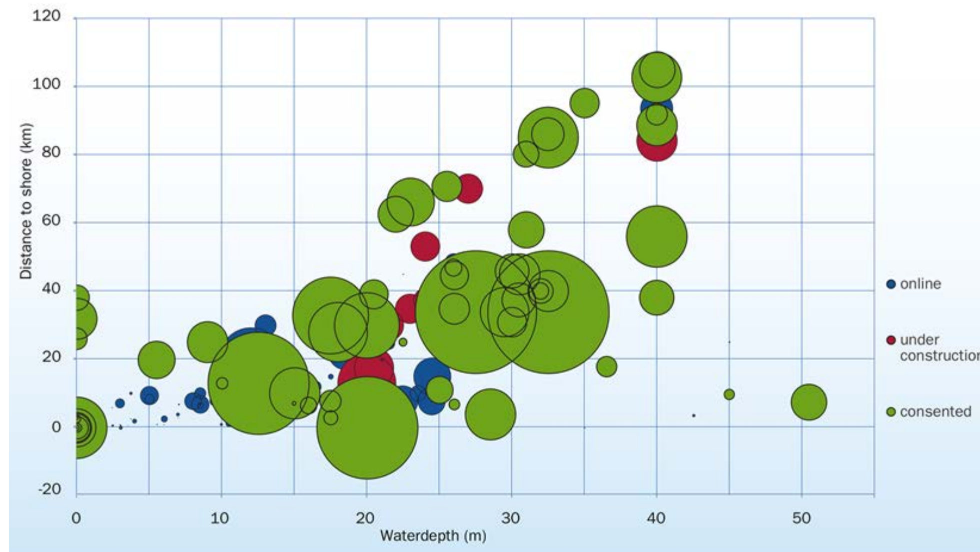
Motivation

Trends in the Offshore Industry:

- Distance to shore ↑
- Water depth ↑
- Turbine size ↑



Source: EWEA, 2014
Berger, 2013



Prototypes have already proven **technical** feasibility of FOWTs

Current Challenge:
Design of **Economic** FOWT Concepts

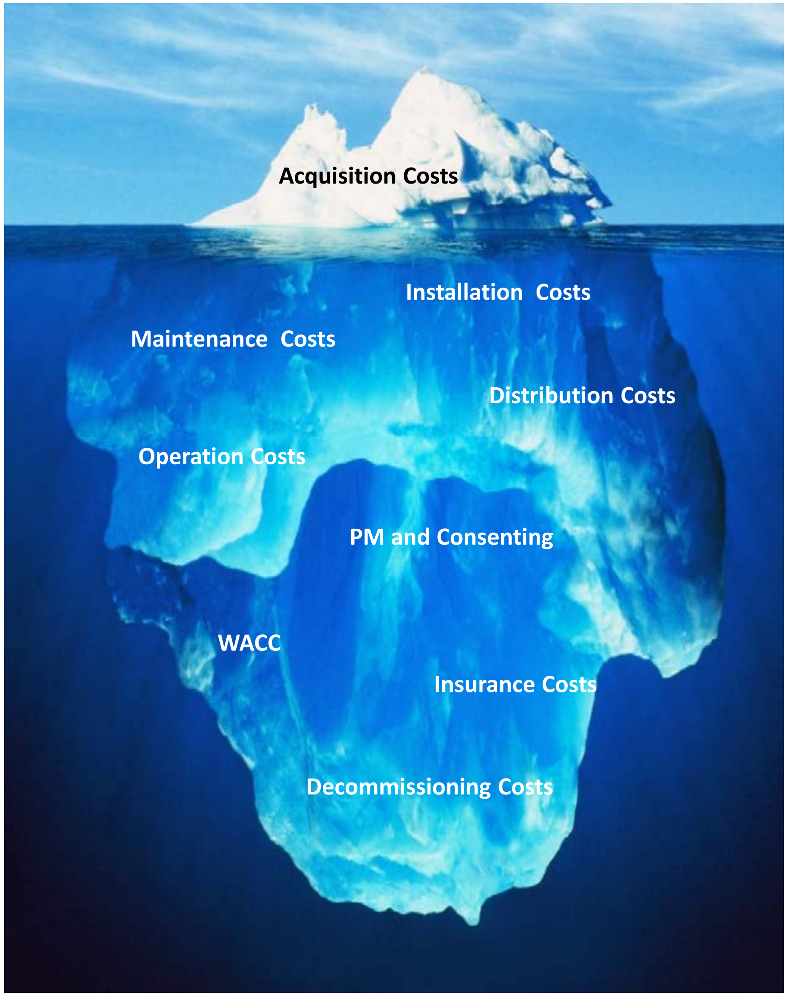
→ LCOE Evaluation required

SWE General Methodology - Economic Evaluation

Approach:

Life-Cycle Cost Analysis

1. **Project Management and Consenting**
2. **Production and Acquisition**
3. **Installation**
4. **Operation and Maintenance**
5. **Decommissioning**

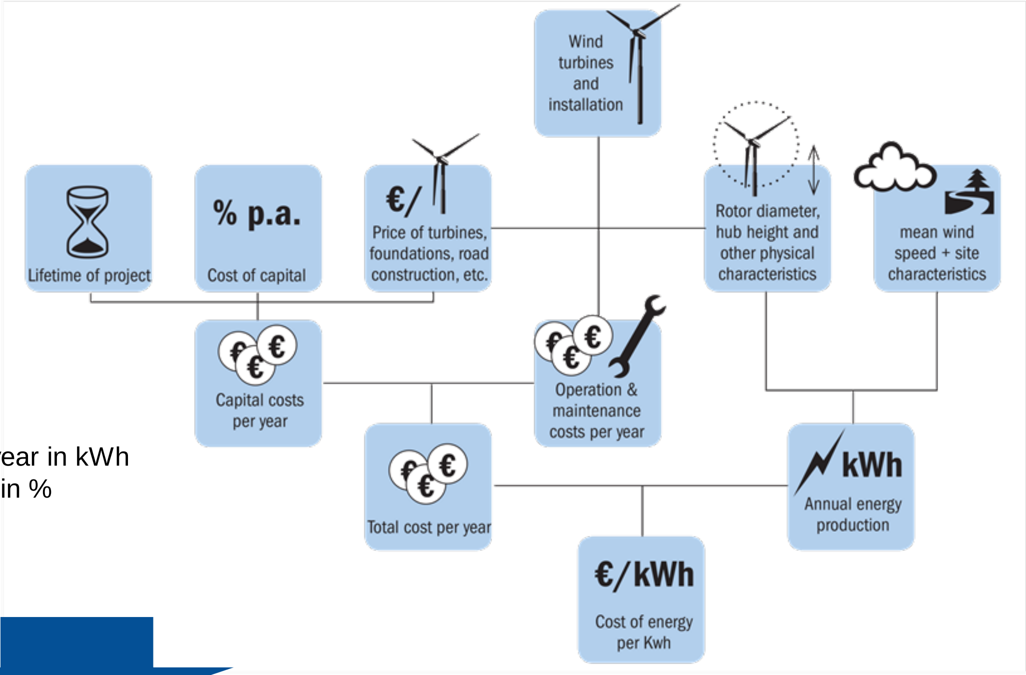


SWE General Methodology - Economic Evaluation

Economic Indicator: **Levelized Cost of Energy (LCOE)**

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

$LCOE$:	Levelized cost of electricity in €ct/kWh
I_0:	Capital expenditure (CAPEX) in €ct
A_t:	Annual operating costs (OPEX) in year t
M_{el}:	Produced electricity in the corresponding year in kWh
i:	Weighted average cost of capital (WACC) in %
n:	Operational lifetime in years
t:	Individual year of lifetime (1,2,…n)



Life-Cycle Analysis approach combined with LCOE to enable an economic assessment and comparison among substructure types

Source: EWEA, 2009

SWE LCOE-Tool – Input Parameter

Implemented Substructure Types:

- Generic steel FOWTs
- Bottom-fixed Solutions
- AFOSP Concept (Concrete Structure)

Site- and Substructurespecific LCOE

Capital costs (CAPEX)

- Consenting/ Development
- Project Management
- Turbine Nacelle
- Turbine Rotor
- Support Structure
- Substation
- Array/Export Cables
- Installation
- Insurance
- Etc.

Operating costs (OPEX)

- Operations and Maintenance
- Operating Phase Insurance
- Transmission Charges
- Seabed Rent
- Etc.

Decommis-sioning costs (DECEX)

- Included: Revenues from recycling and resale

Annual energy production

- Capacity Factor
- Losses
- Availability

Net AEP

Weighted average cost of capital

- Capital structure
- Equity and debt return

Timing

- Phasing of capital and operating costs and energy production over time
- Replacement cycles (Substructure, Turbine)

Directly depending on parameters like "water depth", "distance to nearest operation port" and installed "turbine size"

Manual entries

SWE LCOE-Tool – Level of Detail

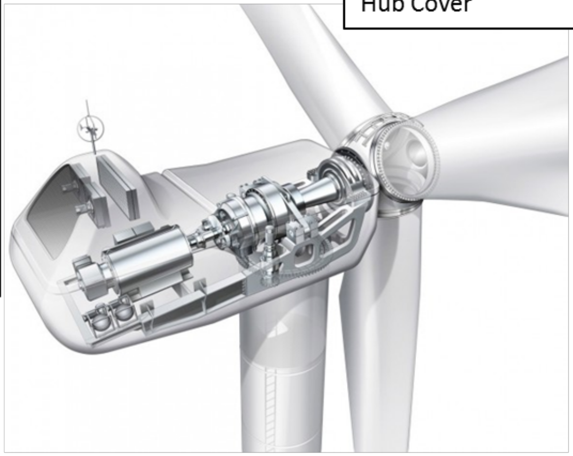
Management activities
Project Consenting and Development
Project Management
Construction Phase Insurance

Grid connection
Array/Export Cables
Internal Substation

Installation
Foundation Installation (incl. Anchor, Mooring lines and Pin Piles)
Tower Installation
Turbine Installation
Array/Export Cable Installation
Internal Substation Installation
Construction contingency

Turbine Nacelle
Gearbox
Electrical Connection
Generator
Main Bearing
Power Electronics
Yaw System
Low-speed Shaft
Others (Mainframe, Aux System, Cover)

Turbine Rotor
Blades
Pitch System
Hub
Hub Cover

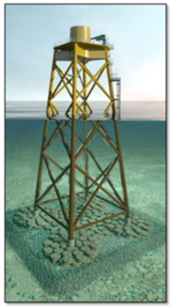


Substructure and Tower

Monopile

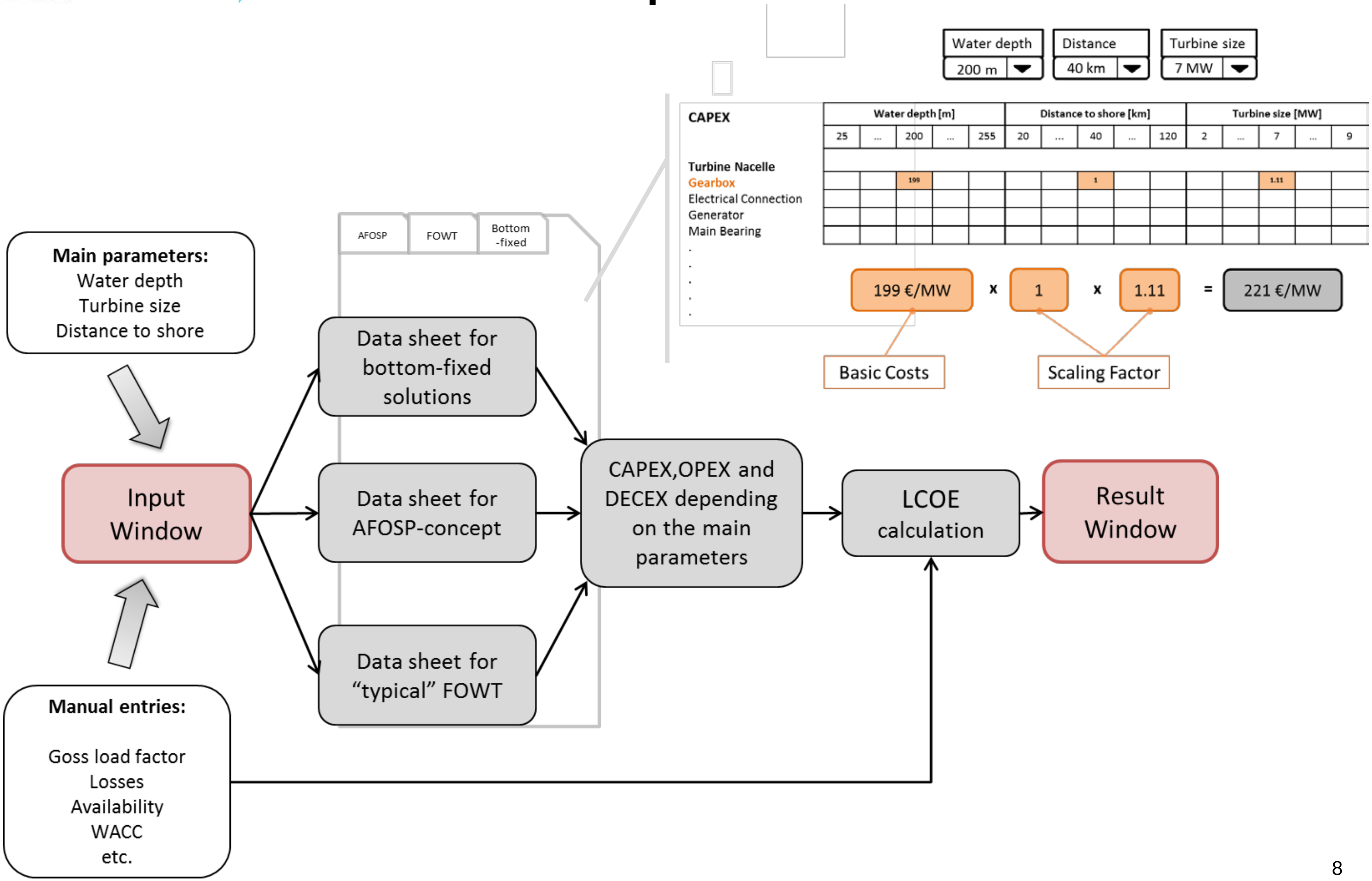
Jacket

Floating Foundation

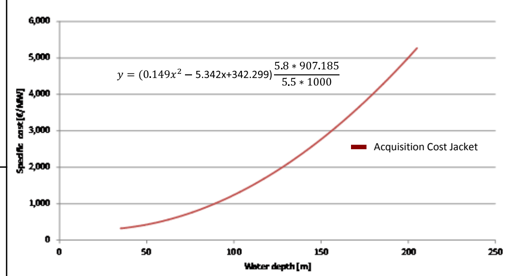
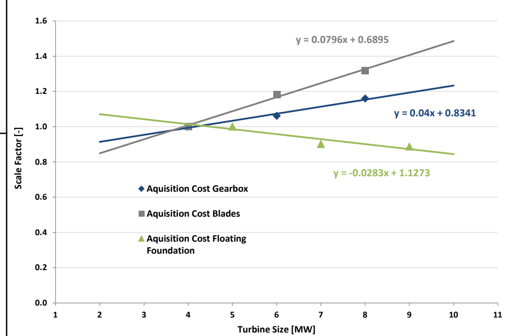


Source: EnBW, 2013
Ramboll Wind, 2013

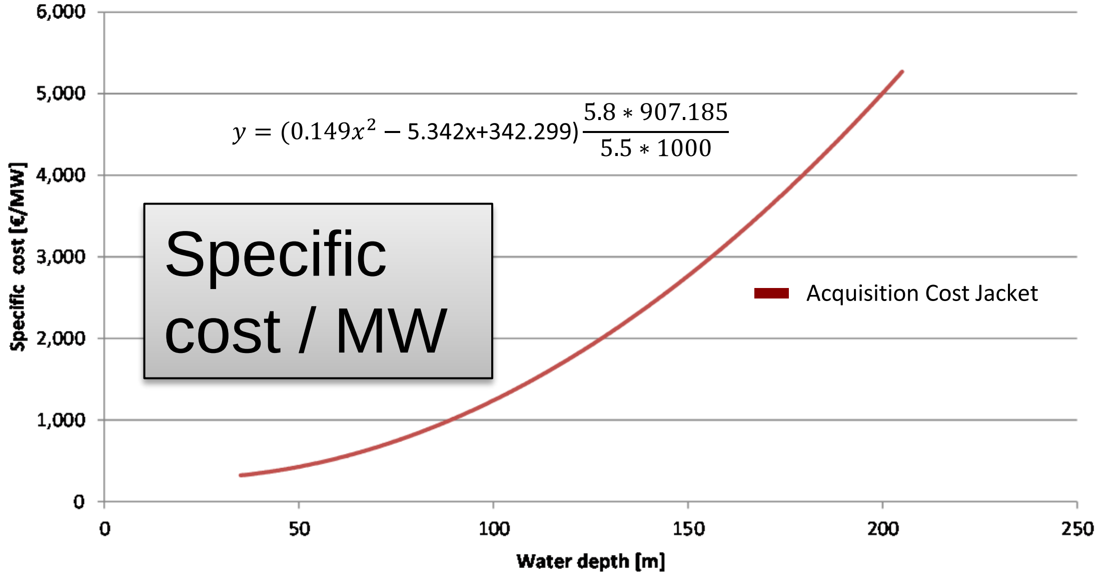
SWE LCOE-Tool – Implementation



SWE LCOE-Tool – Cost functions/Key Assumptions

Summarized Cost categories	Bottom-fixed	Floating	Example Cost functions	Comments/ Key assumptions
Jacket (Monopile in water depths < 35m) Transition Piece	**f(w,t)** 446 000 €/MW	-		• Cost calculation based on weight estimation of jacket/ monopile structures • Specific material and manufacturing costs: 5,8 €/kg
Pin Piles Transition Piece	**f(w,t)** 123 000 €/MW	-		• Conservative approach, due to higher wave loads for deep water sites • Costs for material and manufacturing: 2 €/kg
Floating Foundations	-	**f(t)** 1 252 000 €/MW		• AFOSP: Based on material/production cost estimation • Floating: Mean value of several floating concepts
Turbine (Rotor + Nacelle)	**f(t)** 1 196 000 €/MW	**f(t)** 1 196 000 €/MW		• Turbine model independent from considered type of foundation • As an example for an Rotor- respectively Nacelle-component, the cost function of the gearbox and the turbine blades are illustrated

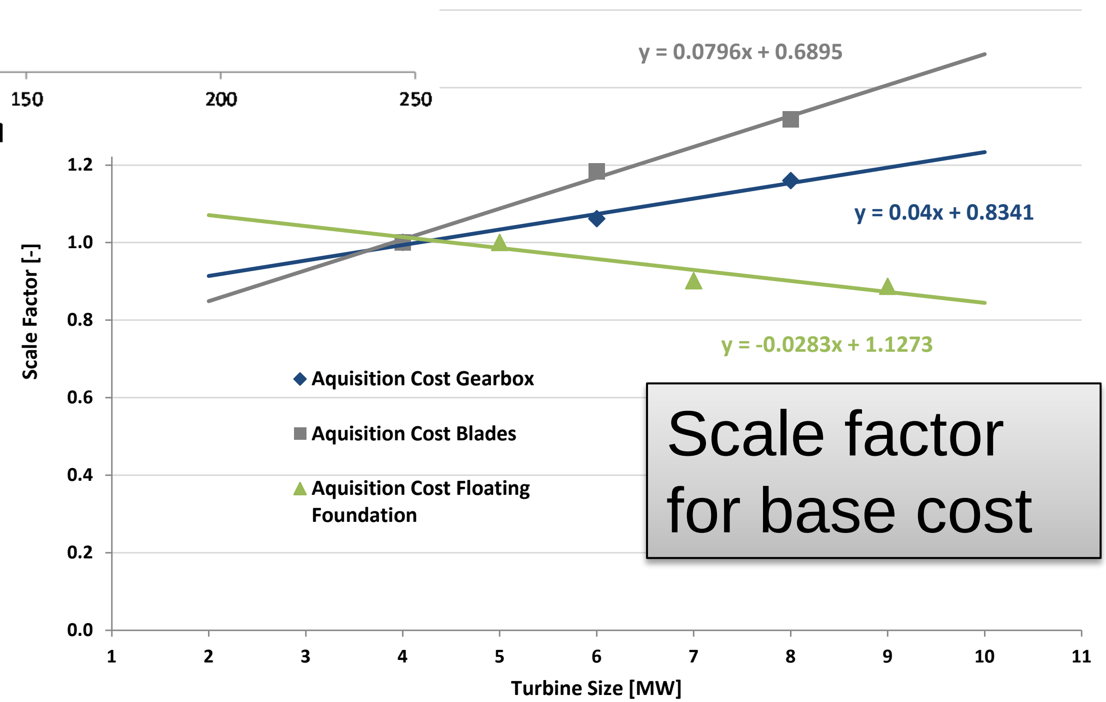
LCOE-Tool – Cost functions/Key Assumptions



Jacket (Monopile in water depths < 35m) Transition Piece	f(w,t) 446 000 €/MW

Floating Foundations	f(t) 1 252 000 €/MW

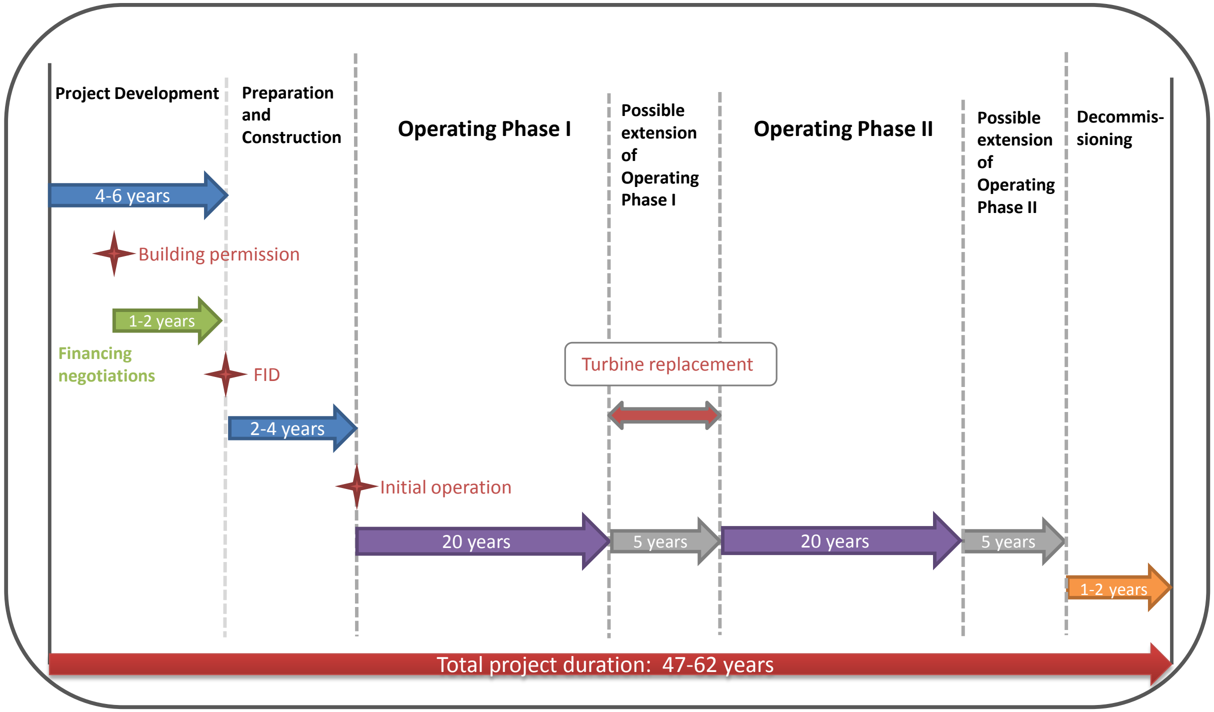
Turbine (Rotor + Nacelle)	f(t) 1 196 000 €/MW

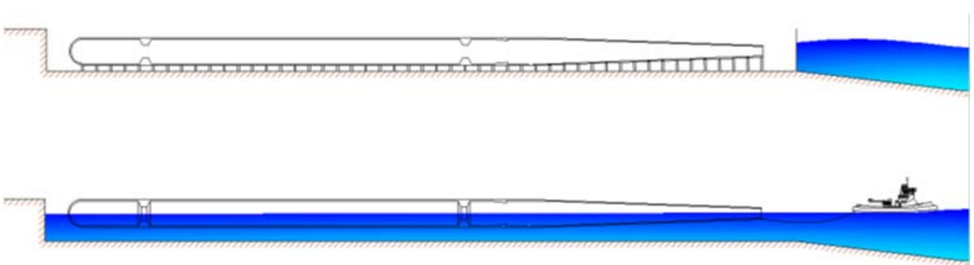


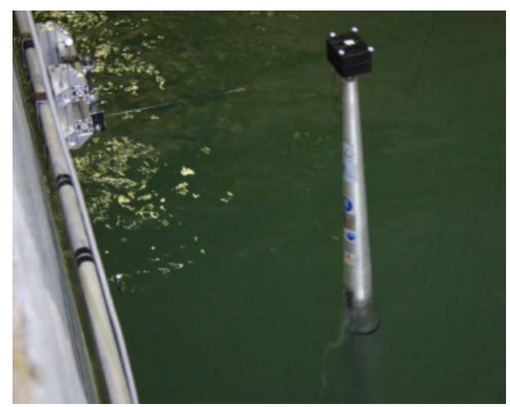
SWE Characteristics AFOSP-Concept

AFOSP-Characteristics:

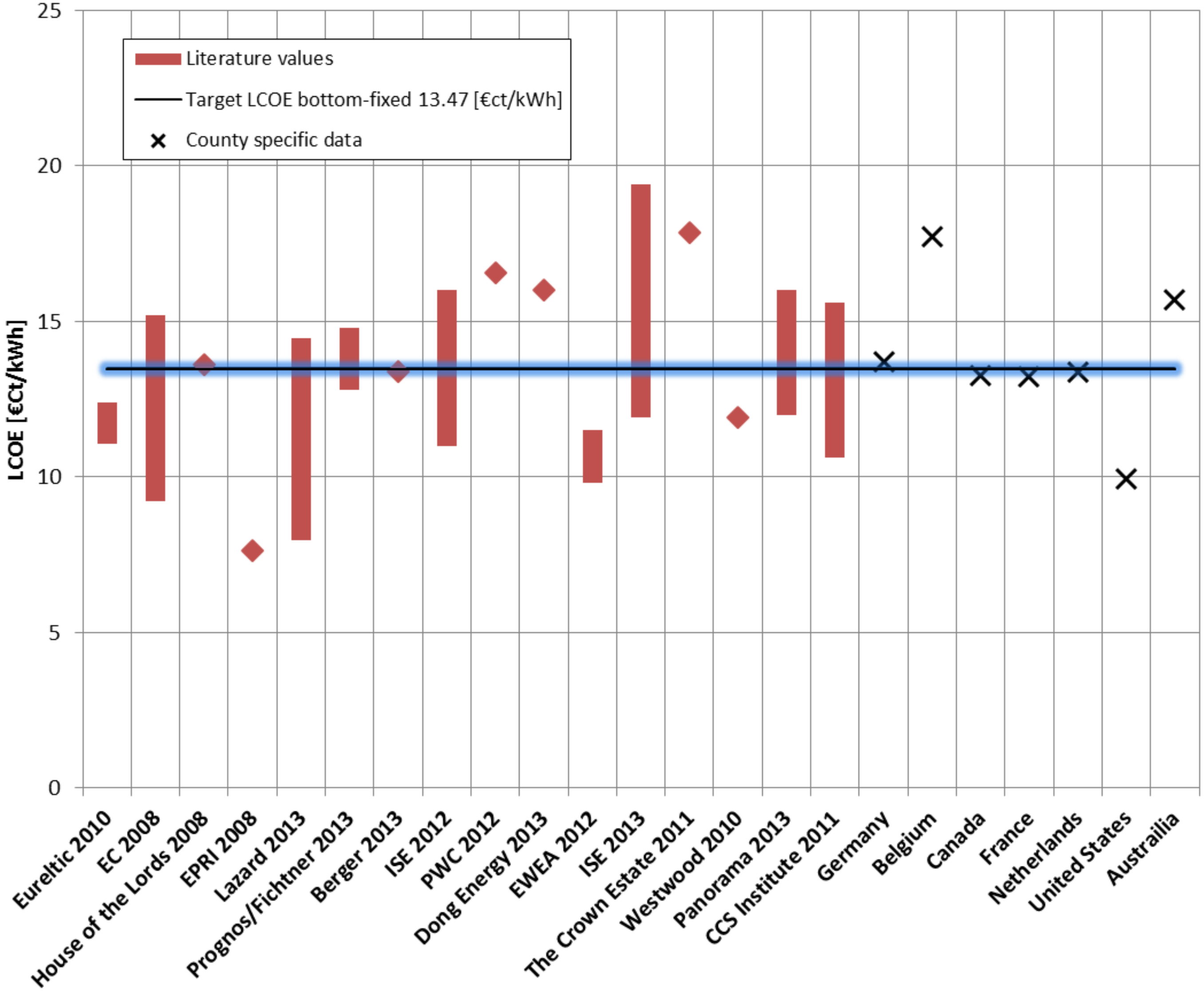
- Monolithic concrete structure
  - Less sensitive to corrosion
  - Reduced O&M effort
  - Lifetime extension of the substructure to 40 or 50 years
  - Relatively simple to manufacture in an automated process (minimum of welds needed)
- Innovative, horizontal Installation process







SWE Current mean LCOE – Fixed-Bottom



13.47 €ct/kWh

- values adjusted for inflation

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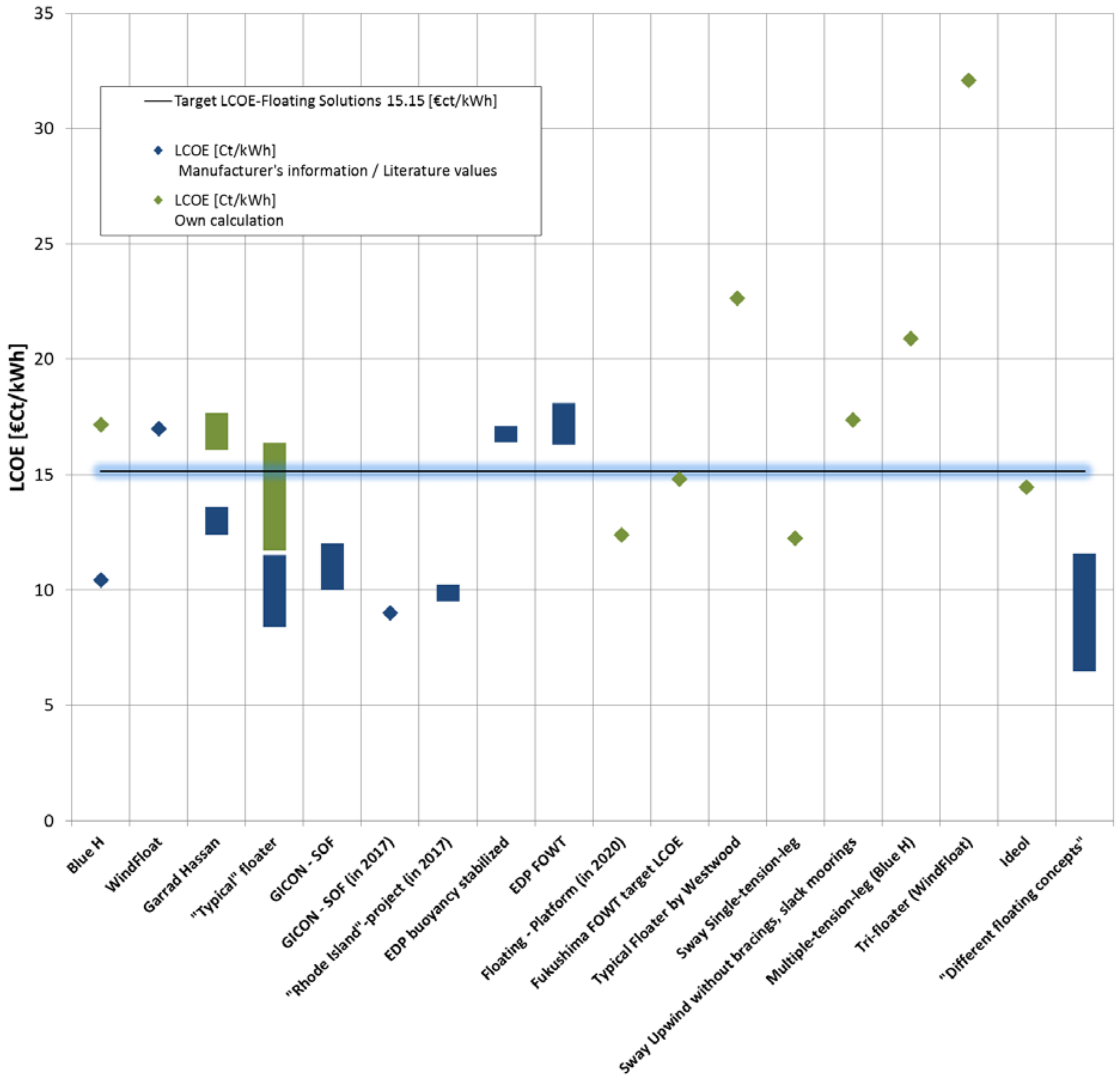
Current mean LCOE - Floating



Difference
Fixed - Floating:
Δ = 1.7 €ct/kWh

15.15
€ct/kWh

- values adjusted for inflation

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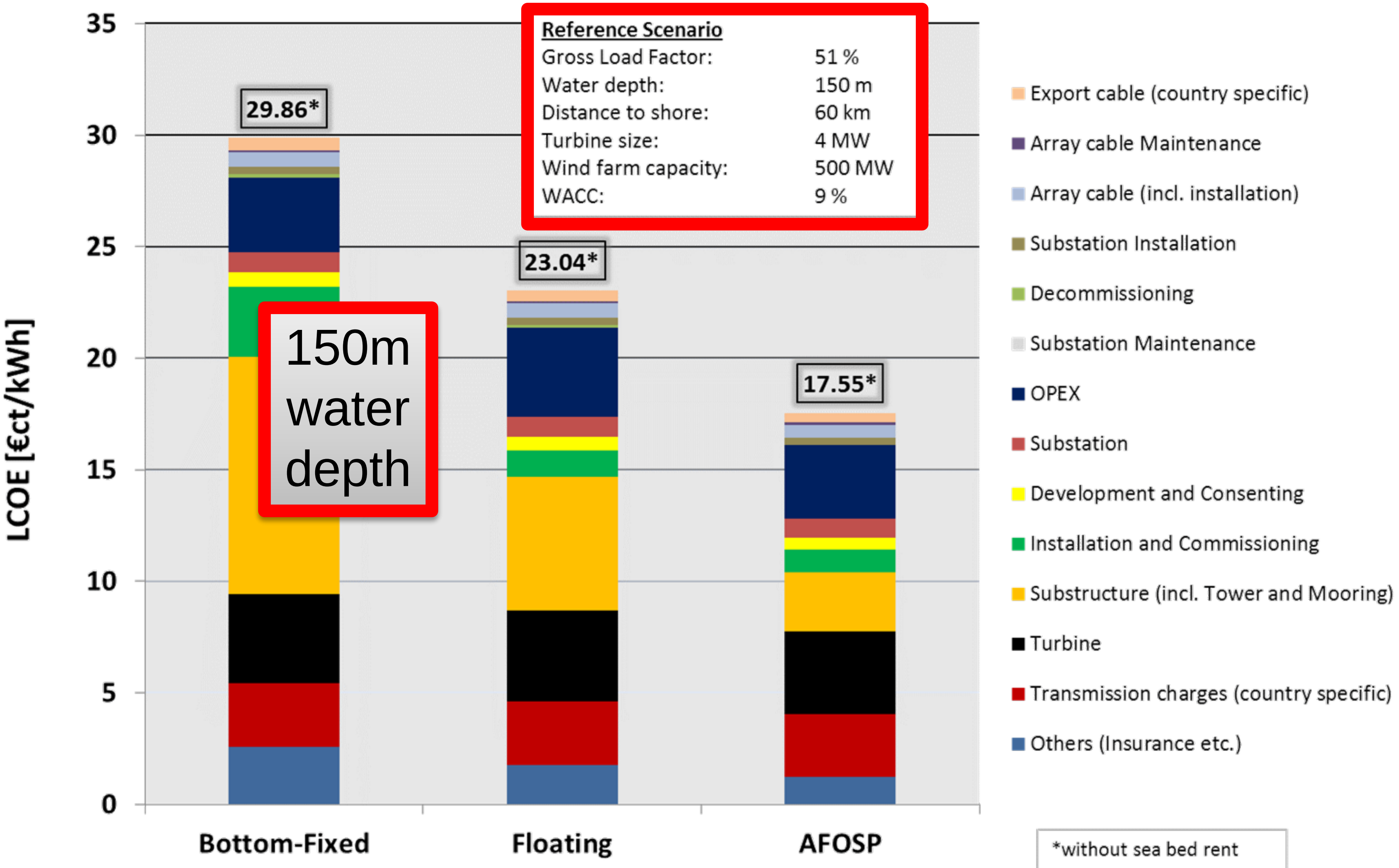
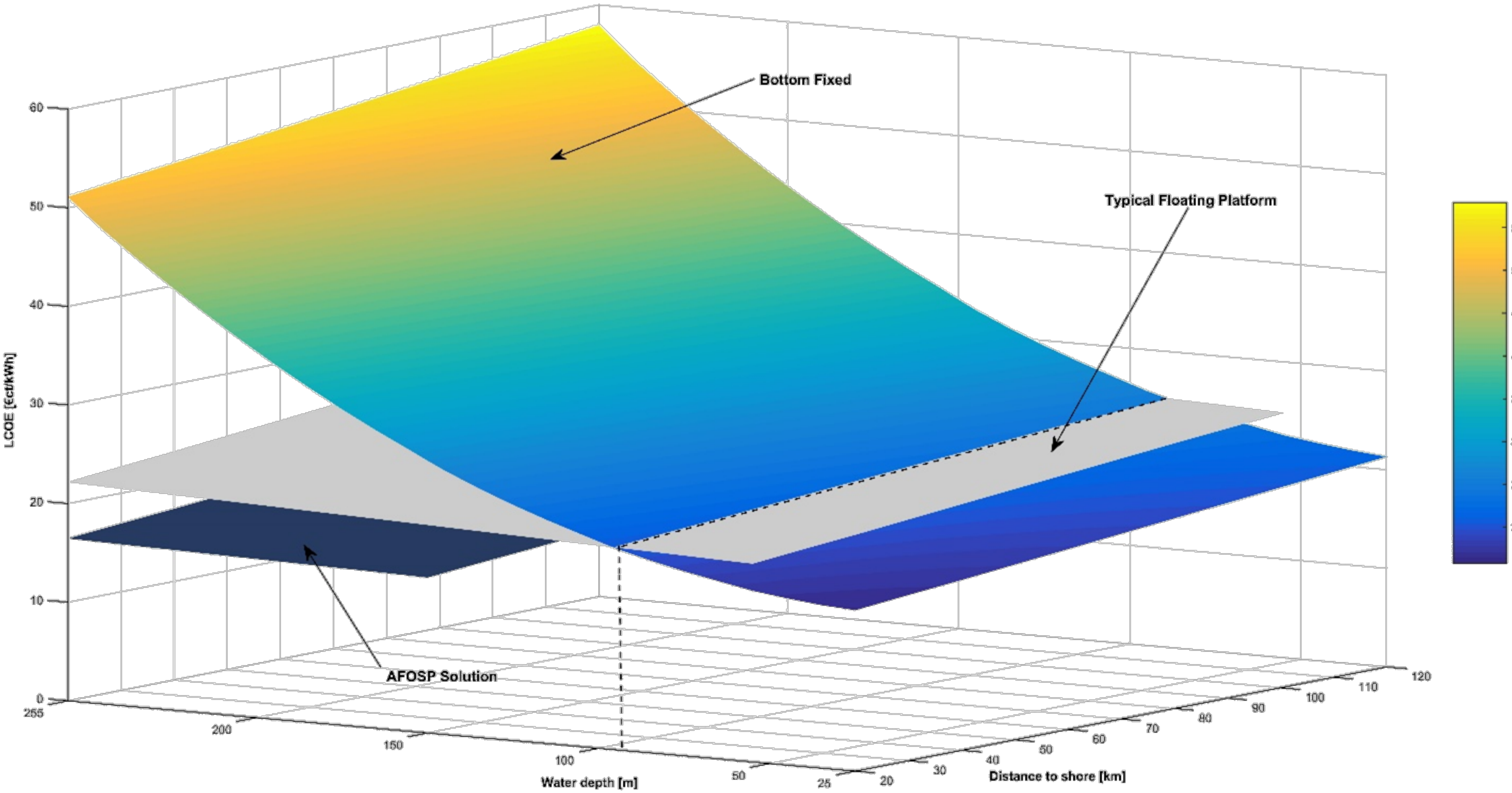
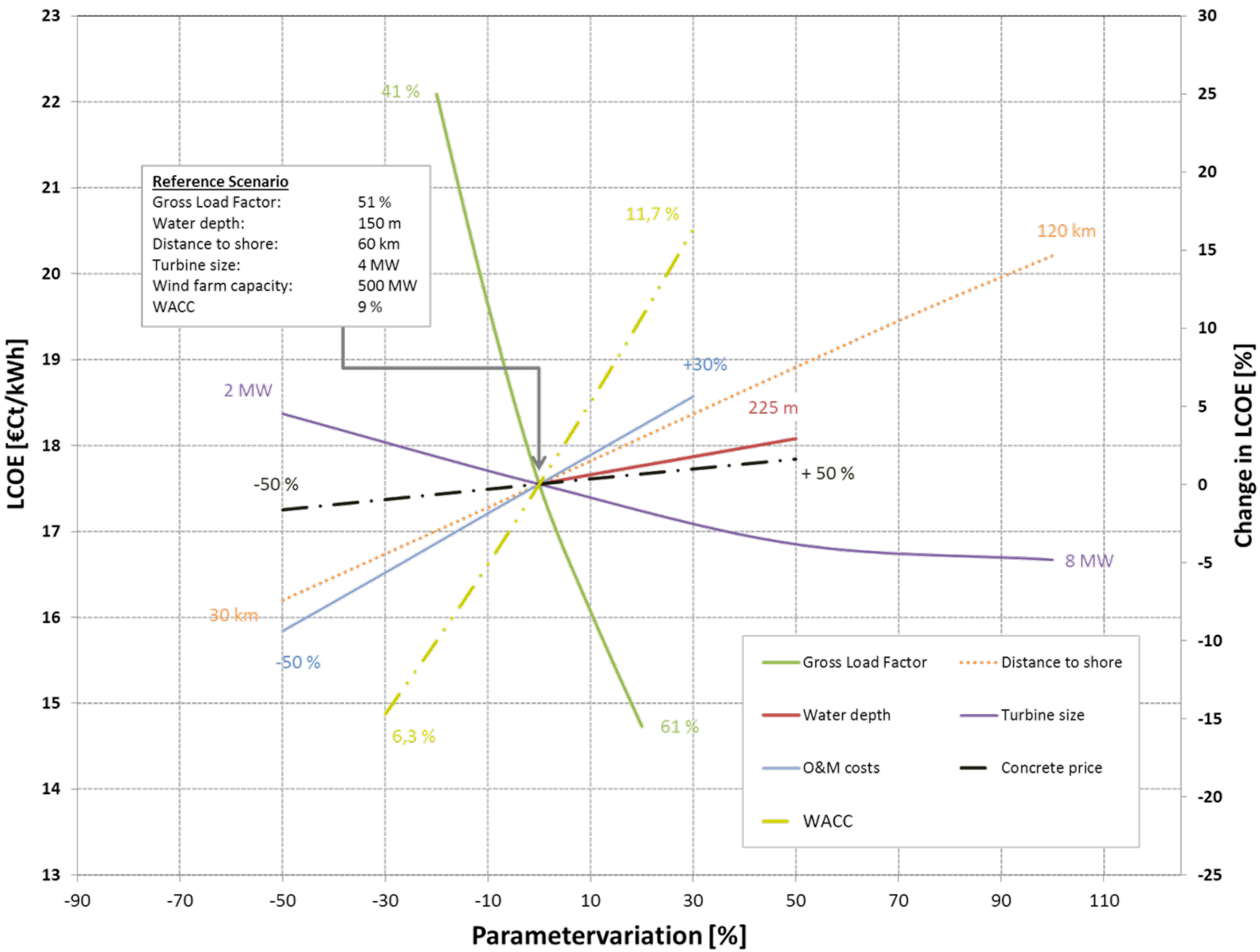
4. Results – Cost Breakdown



4. Results – Sensitivity Analysis Comparison



4. Results – Sensitivity Analysis AFOSP



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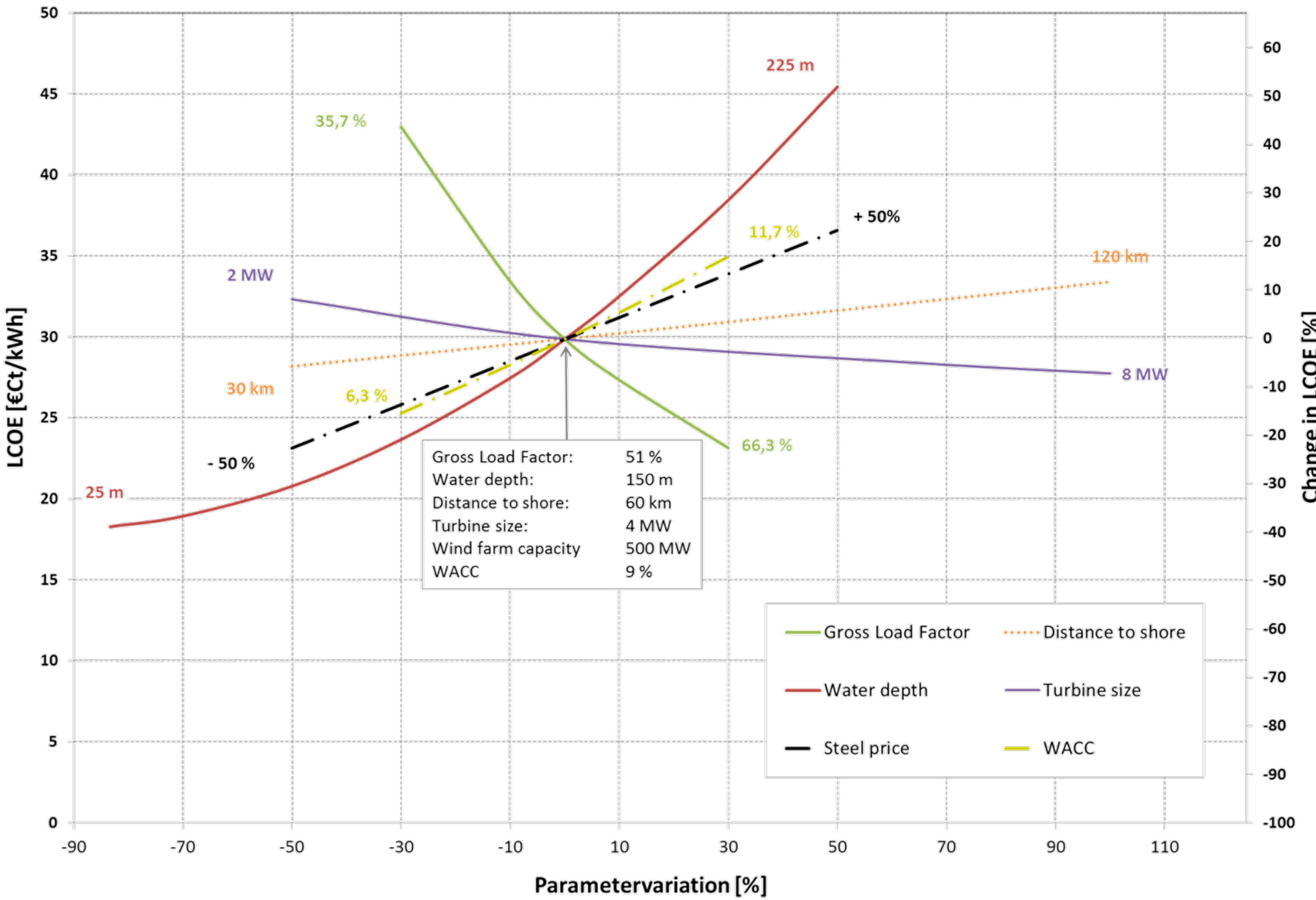
4. Results – Sensitivity Analysis Bottom-fixed



SWE 6. Conclusion/Outlook

- Developed tool helps to optimize the design and reduce the costs of deep offshore wind farms, by analyzing key aspects already during the planning and pre-design phase
- The analyzed concrete design under reference scenario conditions does neither yet reach the estimated benchmark for bottom-fixed structures in shallow waters nor the one representing FOWTs
- Sensitivity analyses illustrate, that even small parameter variations can be decisive and have a huge impact on the total LCOE
- Future technical innovations, learning curve effects and supply chain enhancements are strongly needed for FOWTs to be competitive
- Using existing synergies with the oil and gas industry seems one promising step on the pathway to commercialization

Thank You For Your Attention

WindForS
The Southern German Wind Energy Research Alliance

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