Effects of the Support Structure Design on the Economic Viability of Offshore Wind Projects: an Interdisciplinary Analysis

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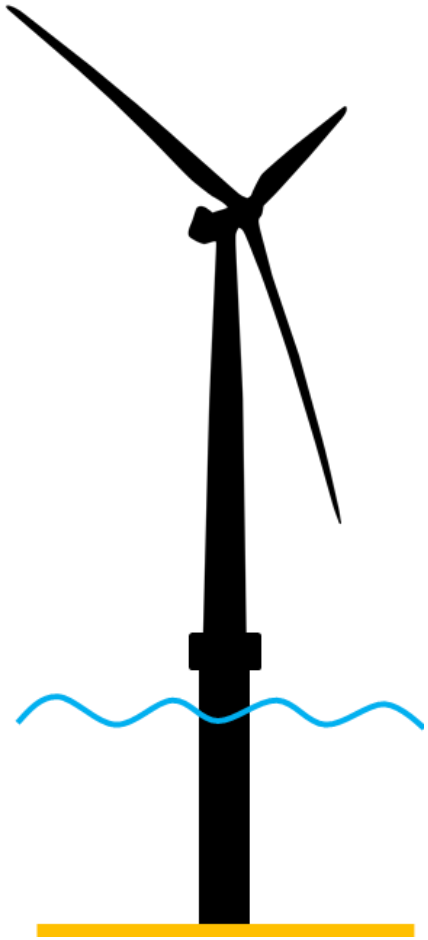
Motivation

Engineering aspects

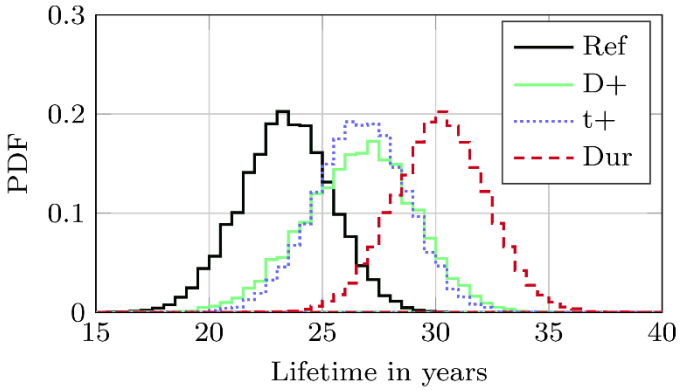
- Offshore wind energy is not yet competitive at current electricity market prices
- “Better” turbines are not always more cost-competitive
- Interdisciplinary optimization is needed

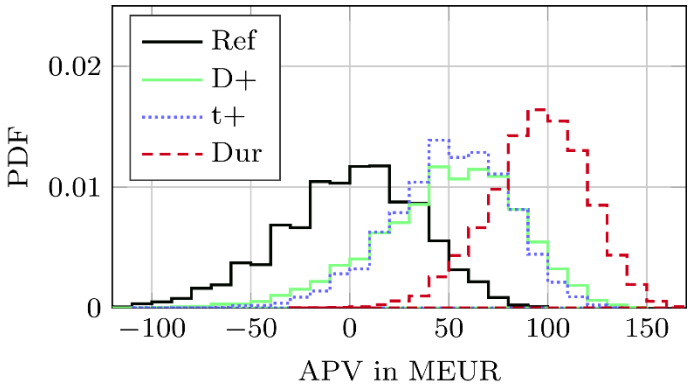
Economic aspects

Outline



- Introduction
- Engineering model
- Economic model
- Test case
- Results
- Conclusions





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Introduction - Objectives

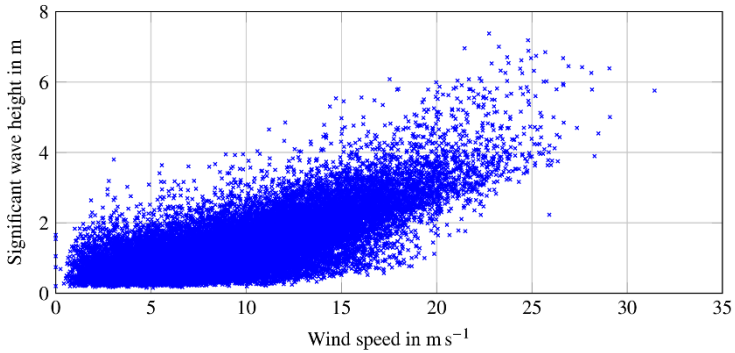
What is the effect of structural design variations on the economic viability of offshore wind farm projects?

⇒ Combine engineering model with economic model

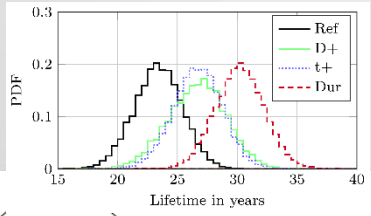
- Use outputs of the engineering model as inputs for the economic model

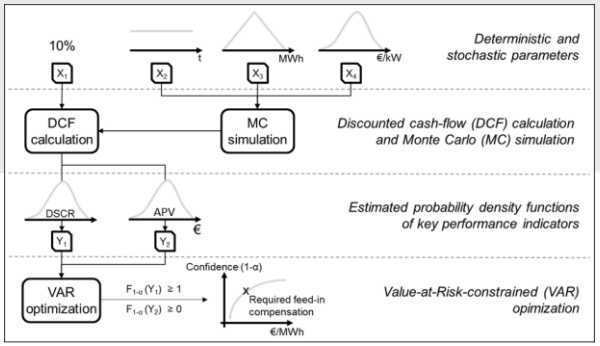
⇒ Probabilistic approach

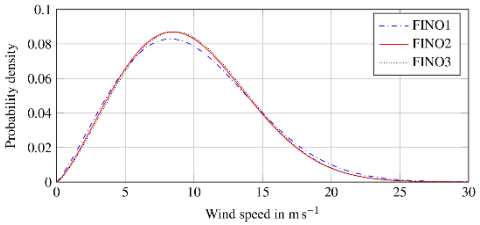
- Use scattering environmental conditions to determine lifetime distribution
- Use scattering wind conditions as well as lifetimes to determine distributions of key performance indicators

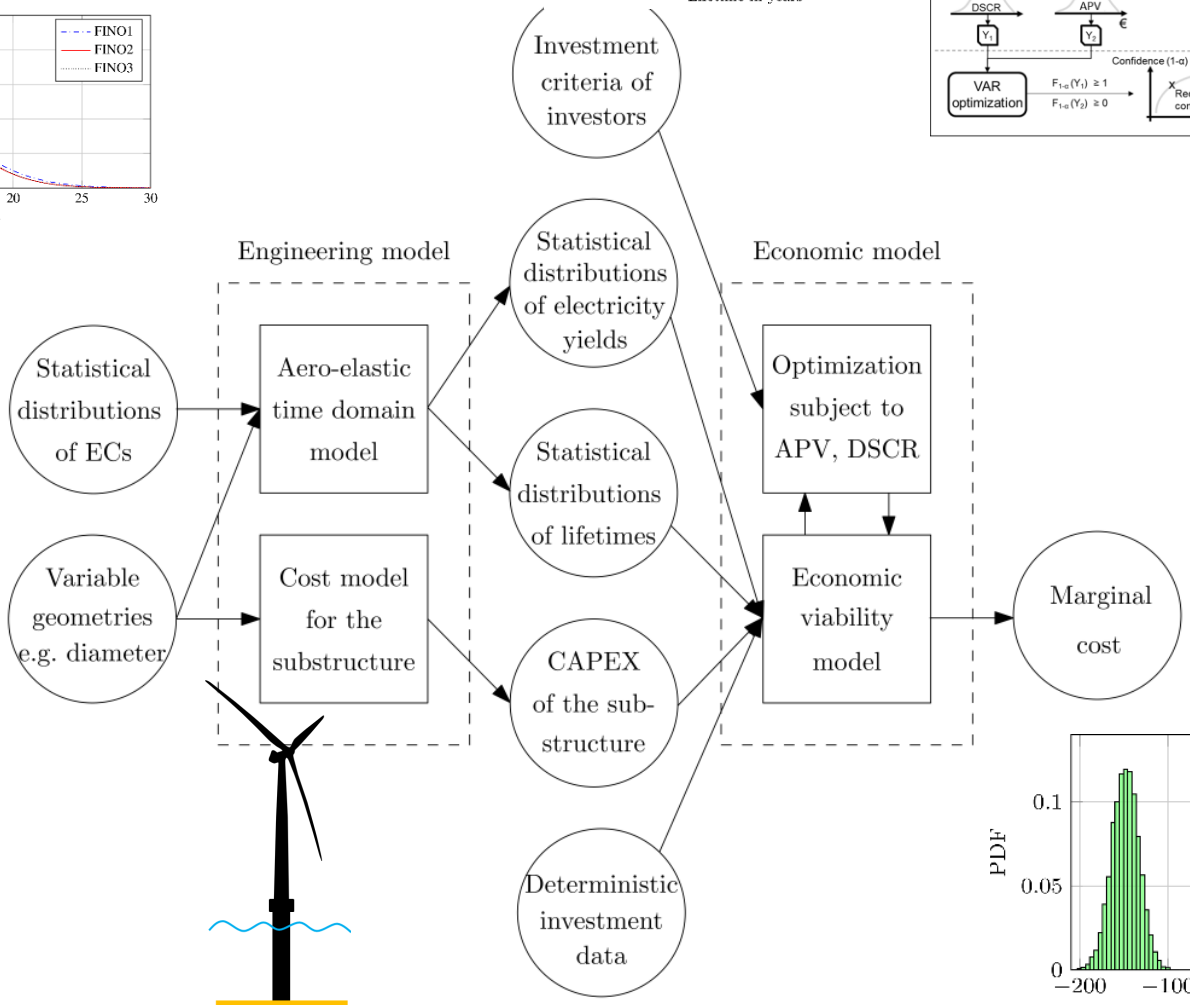


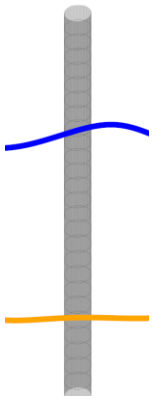
Introduction - Approach

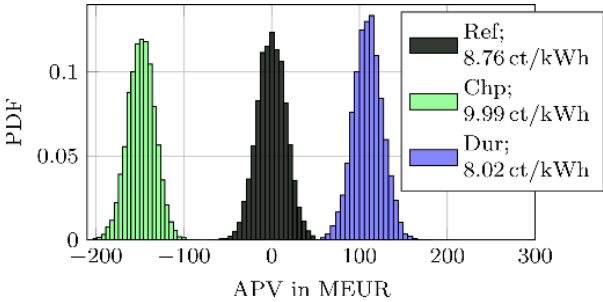












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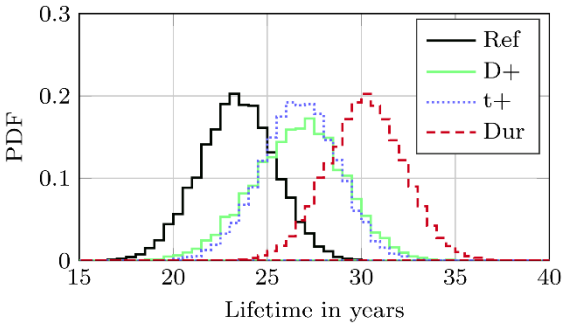
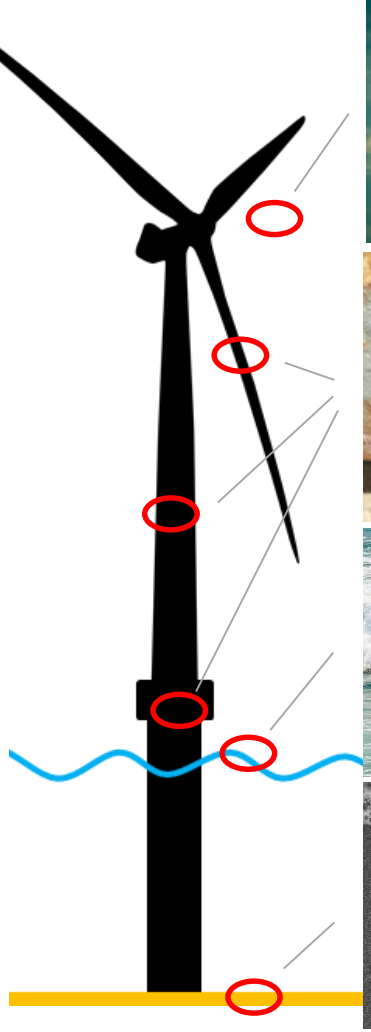
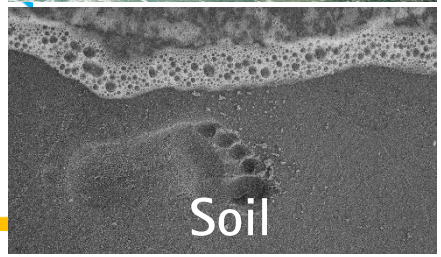
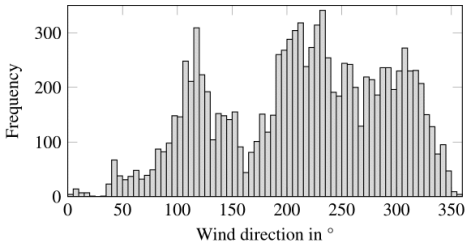
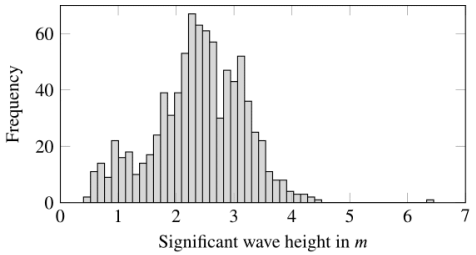
Engineering model (1/3)

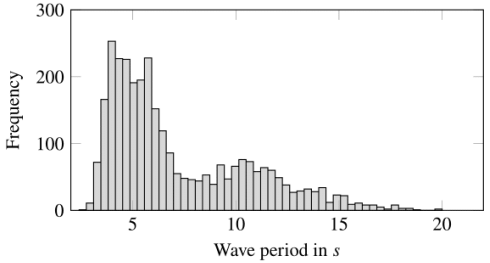








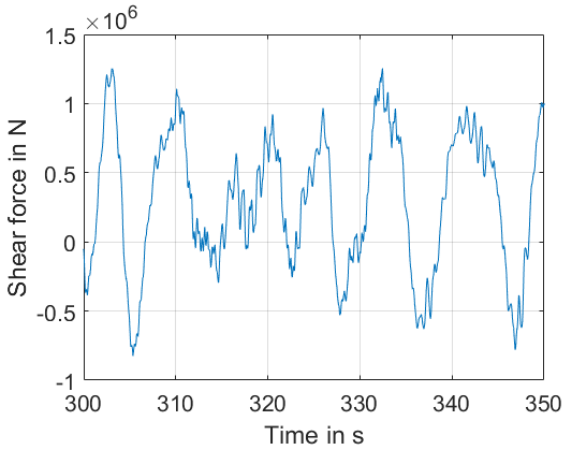


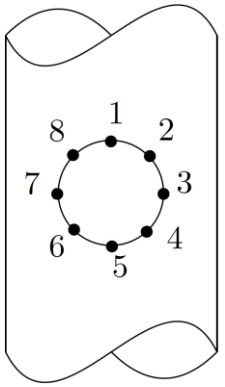


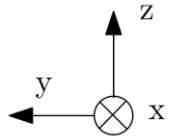
Engineering model (2/3)

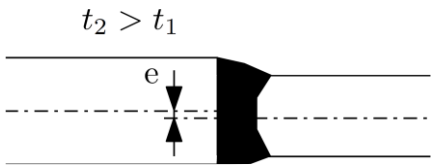
Lifetime-model:

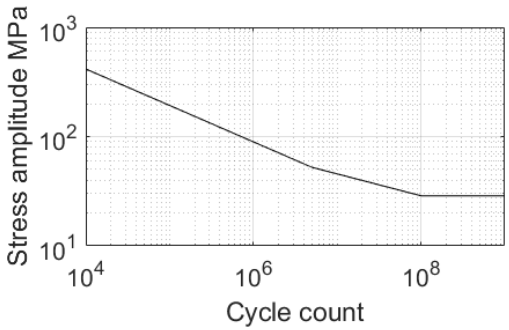
- Load time series
- Calculated stresses
- Hotspot stresses
- Rainflow counting
- S-N curve
- Lifetime calculation

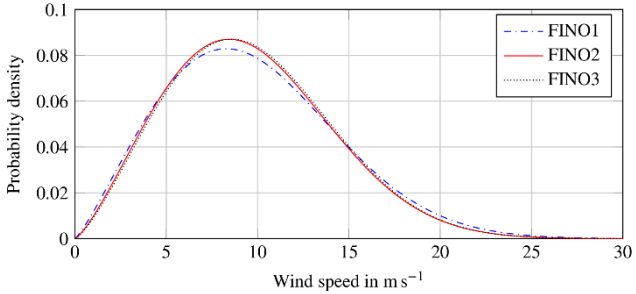












DNV: DNVGL-RP-0005:2014-06 “RP-C203: Fatigue design of offshore steel structures”, RECOMMENDED PRACTICE.
EC3: European Committee for Standardization. (2005). Eurocode 3: Design of steel structures - Part 1-9.

Engineering model (3/3)

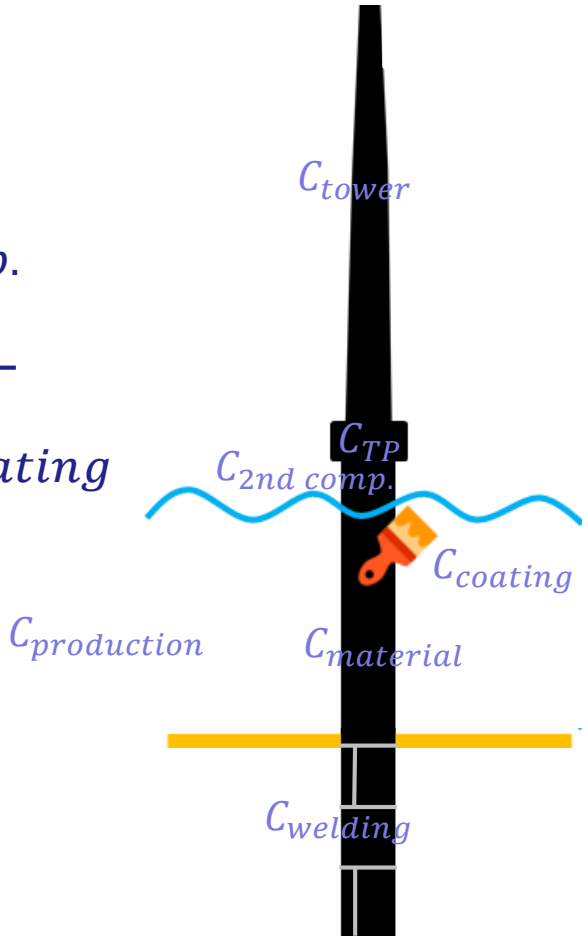
Cost-model:

- Only for substructure
- Summation model for different cost types

$$C_{total} = C_{monopile} + C_{tower} + C_{TP} + C_{2nd\ comp.}$$

$$\text{with } C_{monopile} = C_{material} + C_{welding} + C_{production} + C_{coating}$$

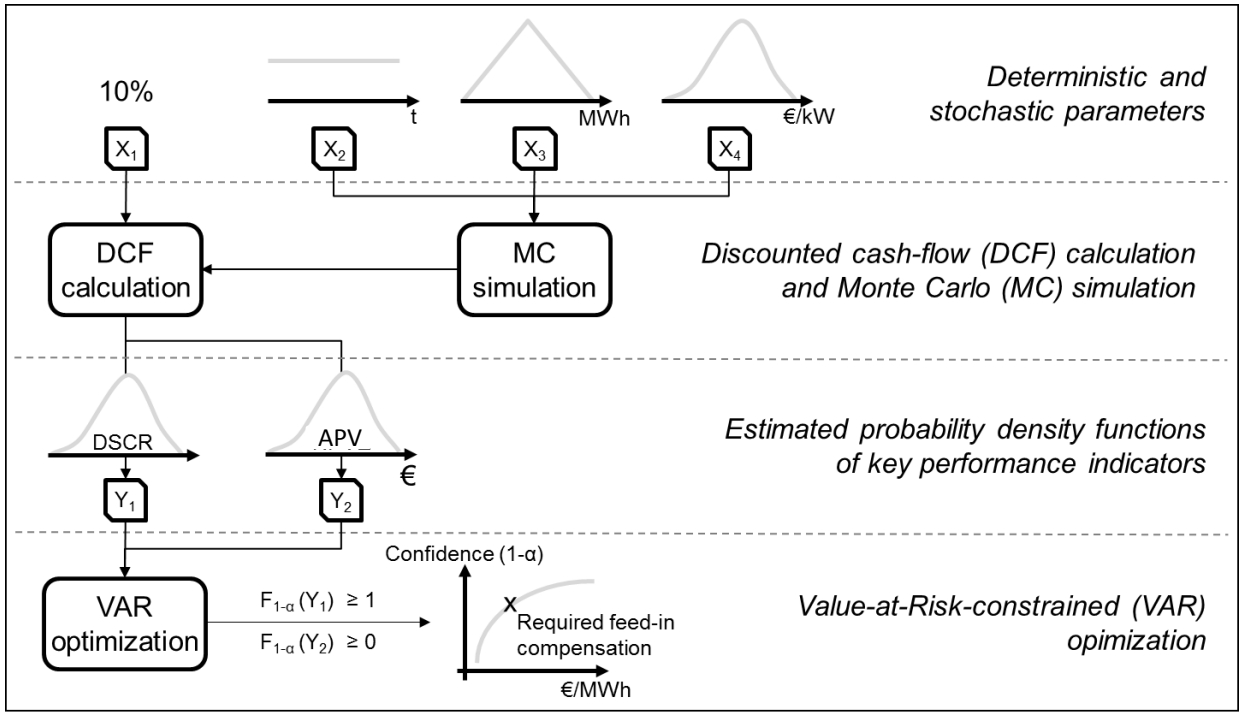
Cost type	Cost
C_{tower}	2500 EUR/t
C_{TP}	2600 EUR/t
$C_{2nd\ comp.}$	5900 EUR/t
$C_{material}$	920 EUR/t
$C_{welding}$	0.33 MEUR/m³
$C_{production}$	0.20 MEUR
$C_{coating}$	200 EUR/m²



Sources: M. Maness, B. Maples, A. Smith, Nrel offshore balance-of-system model, Tech. rep., NREL (2017).
C. Bjerkseter, A. Agotnes, Levelised costs of energy for offshore floating wind turbine concepts, Master's thesis, Norwegian University of Life Science (2013).
W. de Vries, et al., Final report WP 4.2: Support structure concepts for deep water sites: Deliverable d4.2.8, Tech. rep., Delft University of Technology (2011).
E. de Vries, Foundations built on corrosion protection, Windpower offshore, 30 September 2014.

Economic model (1/2)

Economic viability model:



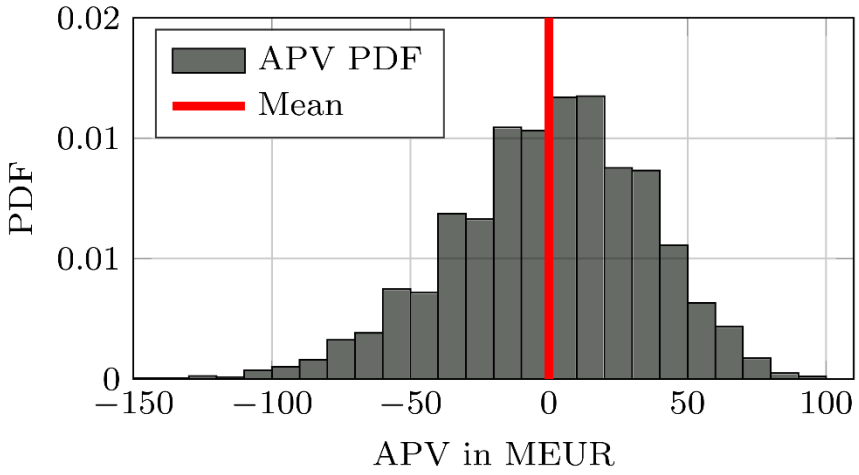
Discounted cash flow calculation:

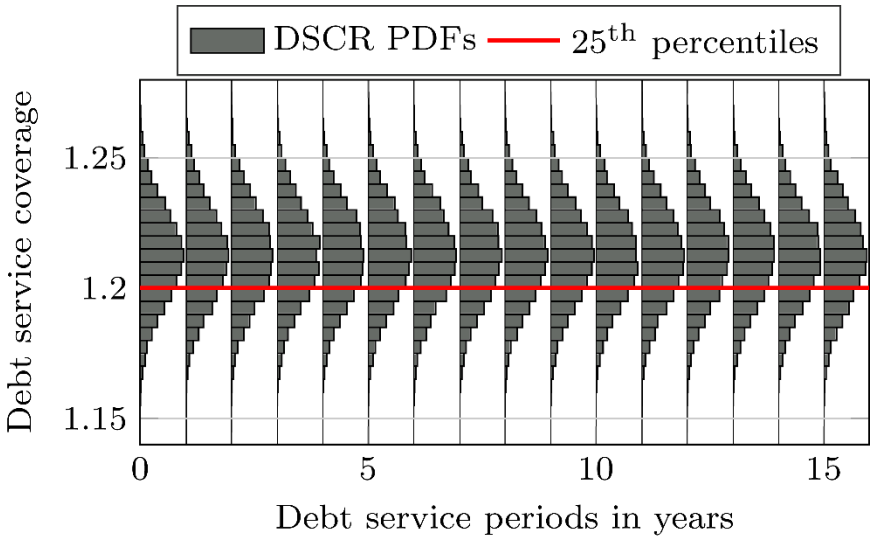
- For calculation of profitability and financial viability key performance indicators
- Is solved 10.000 times in Monte Carlo Simulation

Economic model (2/2)

Investment criteria:

1. Profitable (investors)
2. Financially viable (debt capital providers)

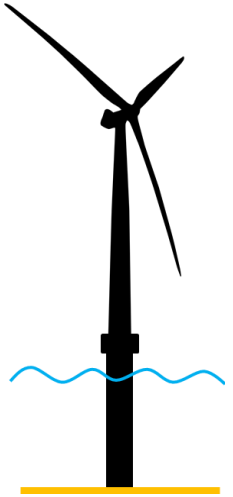




Test case (1/2)

Unchanged engineering reference case:

- NREL 5MW Turbine
- OC3 Monopile
  - Changes in diameters and wall thicknesses of the monopile
- FINO3 environment
- OC3 soil



Parameter	Unit	Value
Wind speed	ms^{-1}	11.4
Turbulence intensity	%	5.27
Wind shear exponent	-	0.0964
Wind direction	°	239
Significant wave height	m	1.65
Wave peak period	s	7.03
Wave direction	°	246

	Abbre-viation	Change in diameter	Change in wall thickness
Reference	Ref	---	---
Increased diameter	D+	+1%	---
Reduced diameter	D-	-1%	---
Increased thickness	t+	---	+2%
Reduced thickness	t-	---	-2%
Durable (Dur)	Dur	+1%	+2%
Cheap (Chp)	Chp	-1%	-2%

Test case (2/2)

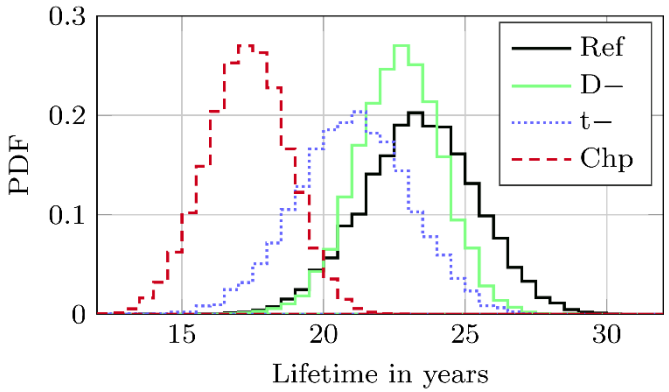
Deterministic reference investment data:

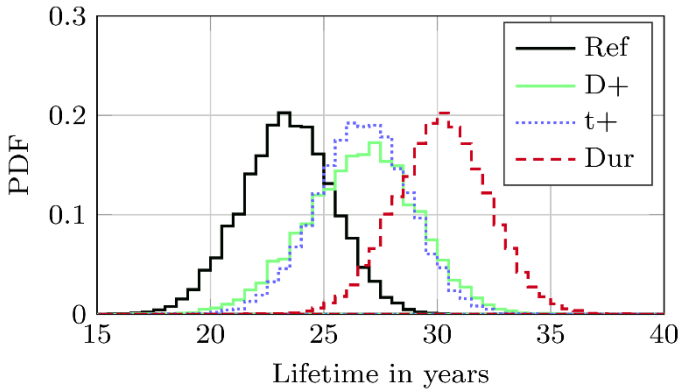
- Cost data is derived from Reimers and Kaltschmitt (2014)
- The financing data is oriented towards Prognos and Fichtner (2013)
- The tax data refers to the German tax legislation

Parameter	Unit	Value	Distribution	Remarks
Capacity	MW	400	Deterministic	-
Wind resource	**m/s**	**-**	**Weibull**	**FINO3 data, same as for the engineering model**
Project duration	**years**	**-**	**Empiric**	**Result of the engineering model**
OW farm efficiency	%	74	Deterministic	-
Corporate tax	%	31	Deterministic	-
Cost of debt	%/a	3.5	Deterministic	-
Unlevered cost of capital	%/a	5.6	Deterministic	-
Capital expenditures	M€	994	Deterministic	Without substructure costs
Operation expenditures	M€	24	Deterministic	-
Decommissioning expenditures	M€	40.8	Deterministic	-

Prognos AG and Fichtner, Kostensenkungspotenziale der Offshore-Windenergie in Deutschland, Tech. rep., Stiftung Offshore-Windenergie (2013).
B. Reimers, M. Kaltschmitt, Kostenentwicklung der Offshore-Windstromerzeugung - Analyse mithilfe der Erfahrungskurventheorie, Zeitschrift für Energiewirtschaft 38 (4) (2014) 217-234.

Results - Engineering part

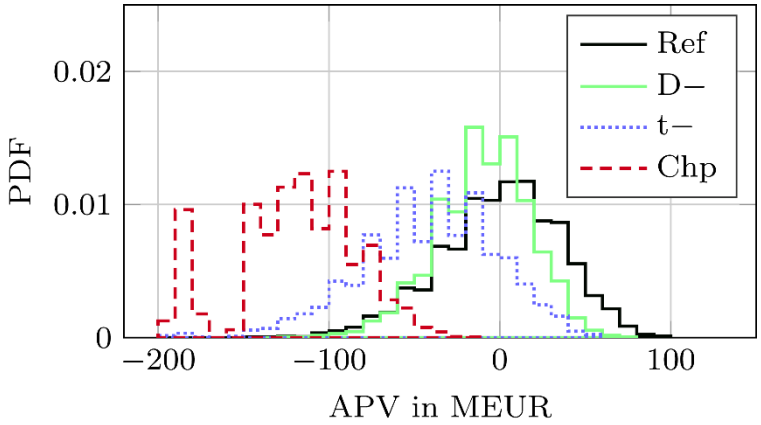


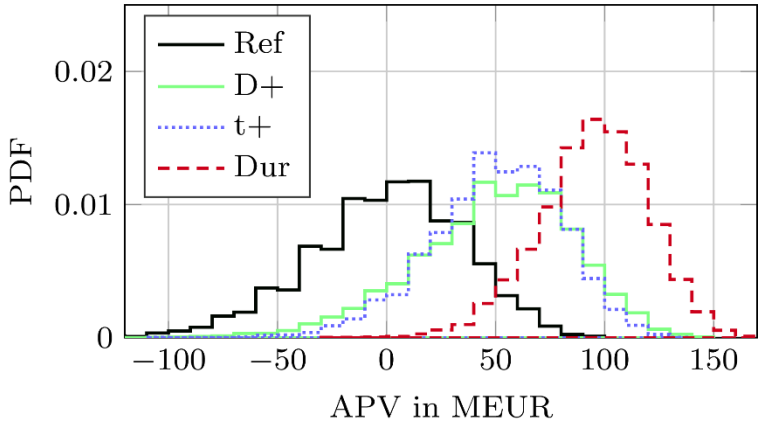


	Abbre-viation	Substructure costs in MEUR	Mean lifetime in years	5th-percentile lifetime in years
Reference	Ref	2.84	23.4	20.0
Increased diameter	D+	2.87 (+1.1%)	26.6 (+13.9%)	22.6 (+12.8%)
Reduced diameter	D-	2.81 (-1.1%)	22.7 (-3.1%)	20.2 (+0.8%)
Increased thickness	t+	2.88 (+1.3%)	26.7 (+14.2%)	23.3 (+16.5%)
Reduced thickness	t-	2.80 (-1.3%)	21.0 (-10.1%)	17.7 (-11.3%)
Durable (Dur)	Dur	2.91 (+2.5%)	30.2 (+29.2%)	26.8 (+34.2%)
Cheap (Chp)	Chp	2.88 (-2.3%)	17.3 (-26.0%)	14.9 (-25.6%)

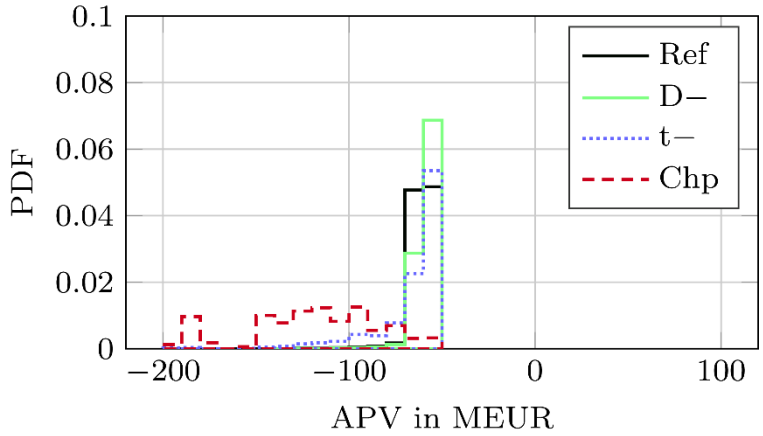
Results - Economic part

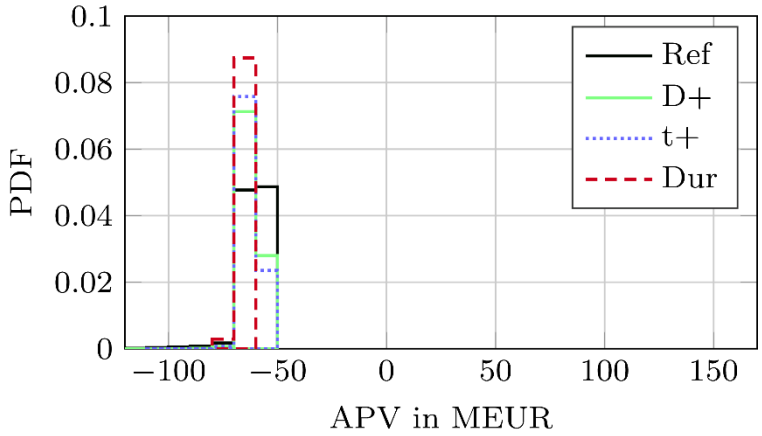
Unlimited lifetime (limitation by substructure lifetime)





Lifetime limited to 20 years

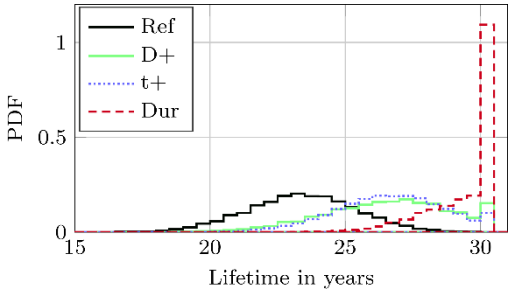


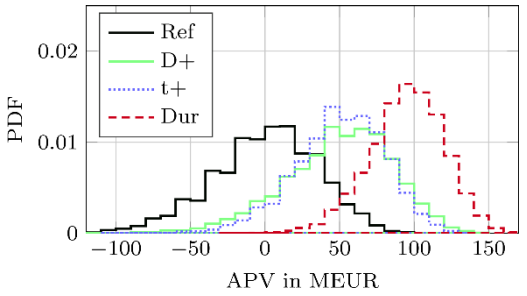


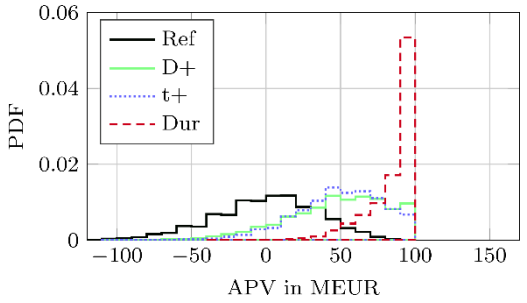
Conclusions

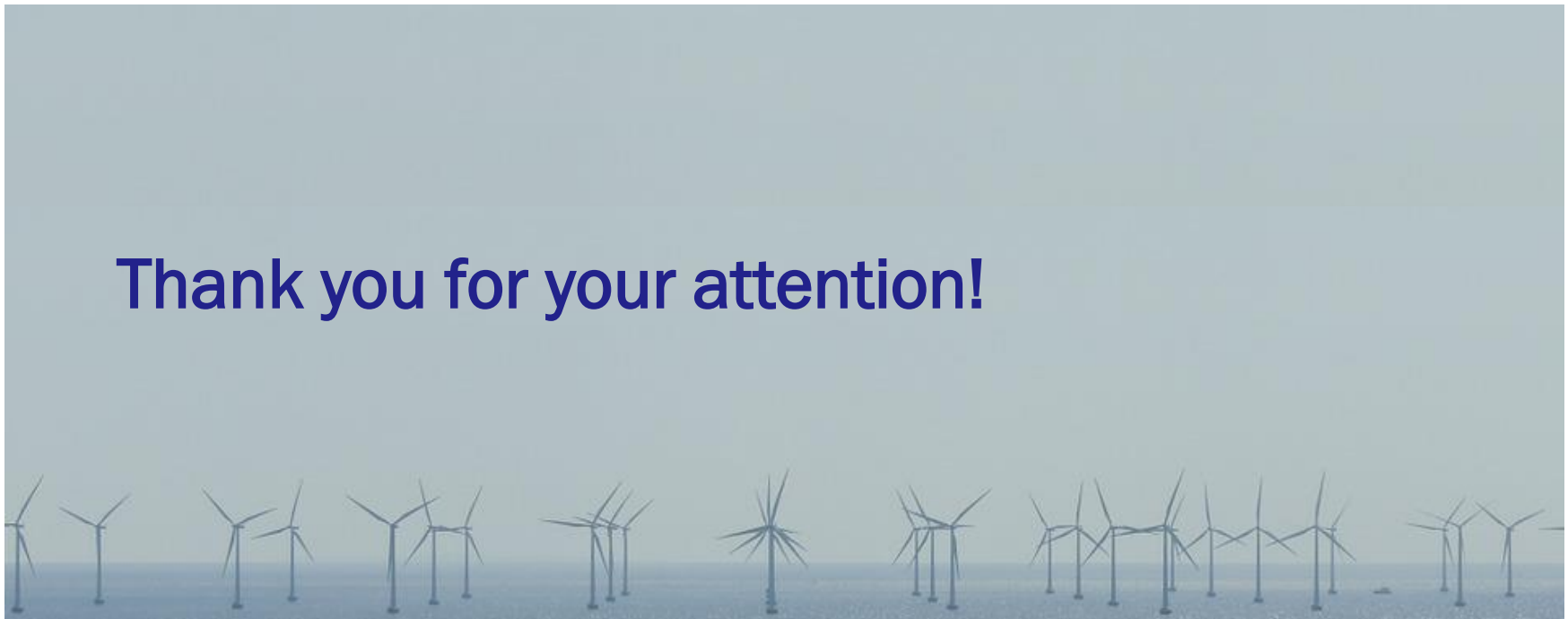
- Approach gives real assistance for investment decisions
- Only substructure was modified ⇒ other components should follow
- Only design variations, no complete new designs
- Only substructure lifetime ⇒ unrealistic lifetime extensions?
- No insurances are considered

⇒ A lot of work to do (Project proposal - InterWind)









Thank you for your attention!

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