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Combined economic-environmental design of offshore wind farms

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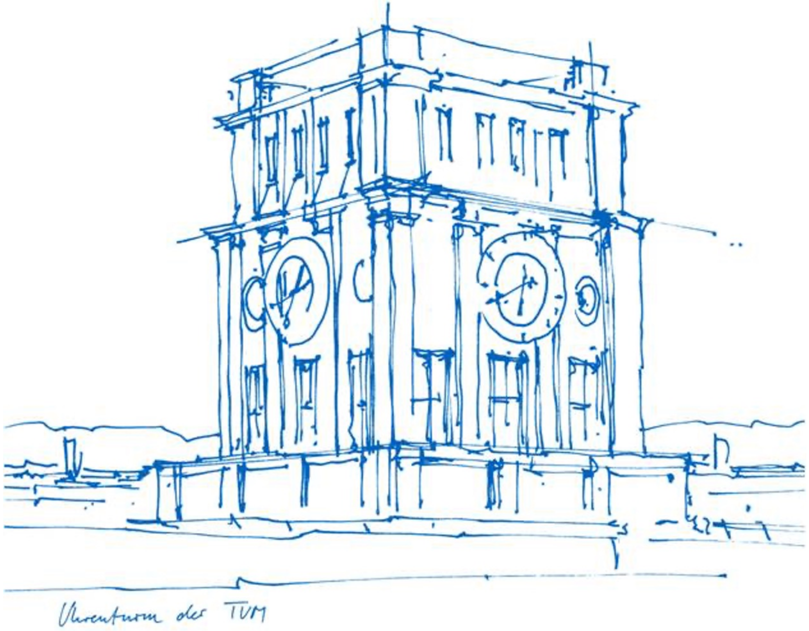


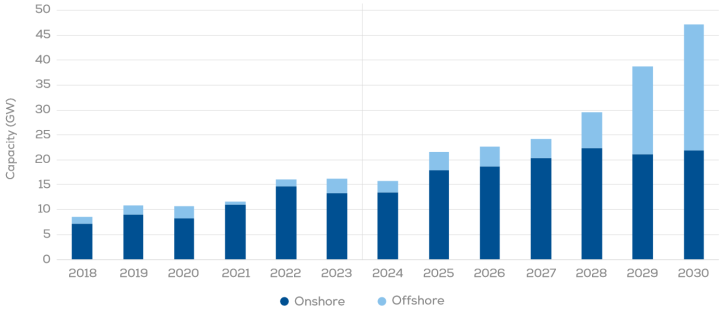
Introduction

- Wind energy is reaching cost parity
- Massive growth targets of the sector
- Upcoming environmental requirements in offshore tenders

➔ Wind farm design and operation beyond LCOE to concurrently ensure economic and environmental sustainability

➔ DETECT (Design and Evaluation Toolchain with Eco-Conscious Targets)

Annual wind power installations in EU[1]



[1]WindEurope (2024): “Wind energy in Europe - 2023 Statistics and the outlook for 2024-2030”

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Metrics of interest

	Economic			Environmental		
Cost	**$COE_{€}$**	Levelized cost of energy	Total life cycle costs / Total energy production	**COE_{CO2}**	Carbon footprint	Total life cycle emissions / Total energy production
Value	**$VOE_{€}$**	Revenue	Total monetary production / Total energy production	**VOE_{CO2}**	Displaced Grid-GHG	Total displaced emissions / Total energy production
Net Value	**$NVOE_{€}$**	Profit	$VOE_{€} – COE_{€}$	**$NVOE_{CO2}$**	Avoided Grid-GHG	$VOE_{CO2} – COE_{CO2}$
Unit	€/MWh			$kgCO_2eq/MWh$		

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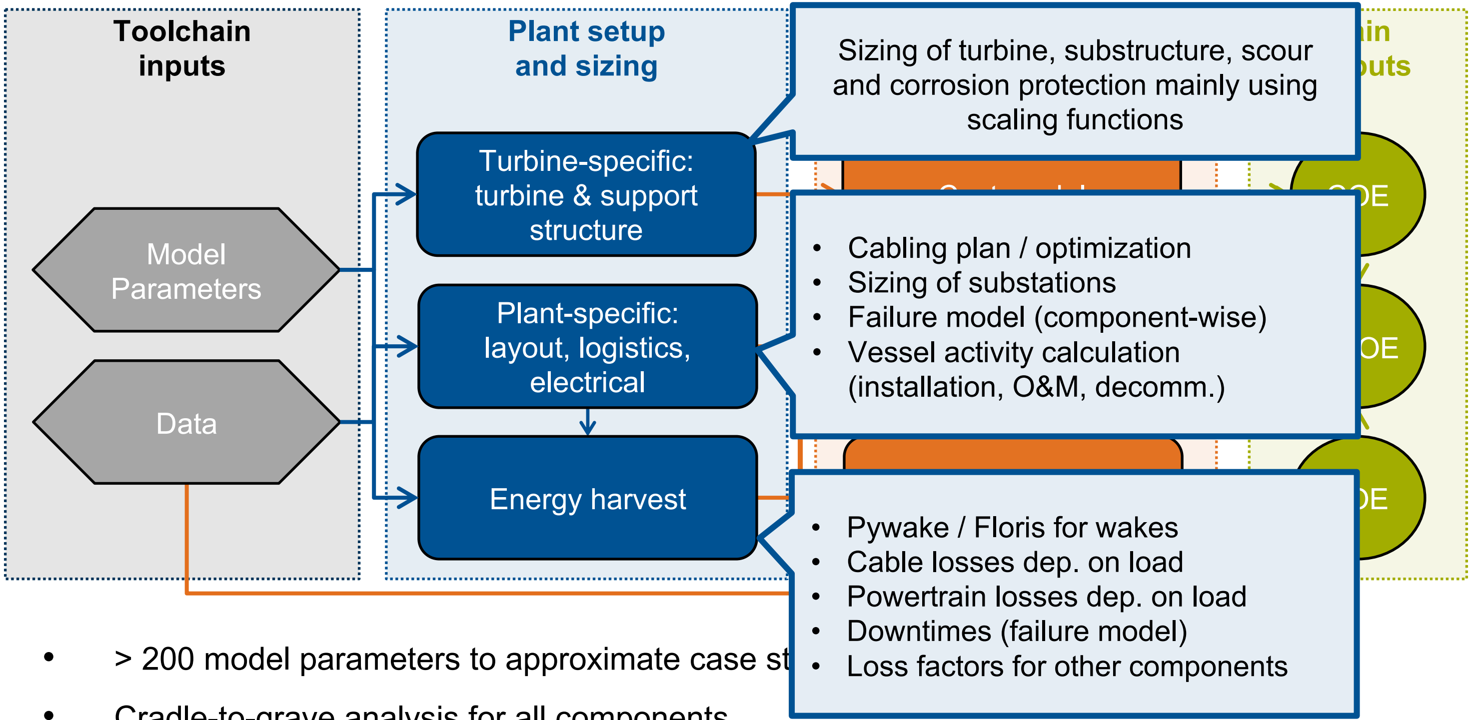
Method



- > 200 model parameters to approximate case st
- Cradle-to-grave analysis for all components
- Result breakdown per life stage, component, and material

Method

Toolchain inputs

Model Parameters

Data

- Based on WISDEM, TopFarm, CATAPULT
- Extended with transport and end-of-life cost functions
- Scaled, discounted and converted to 2020-Euros

- Assessment of climate change impact from cradle to grave
- based on >100 ecoinvent reference activities
- ~30 components & ~30 materials

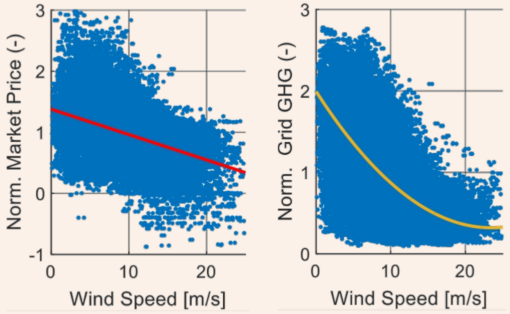
Cost & Value analysis

Cost model

LCA model

Market & Grid model

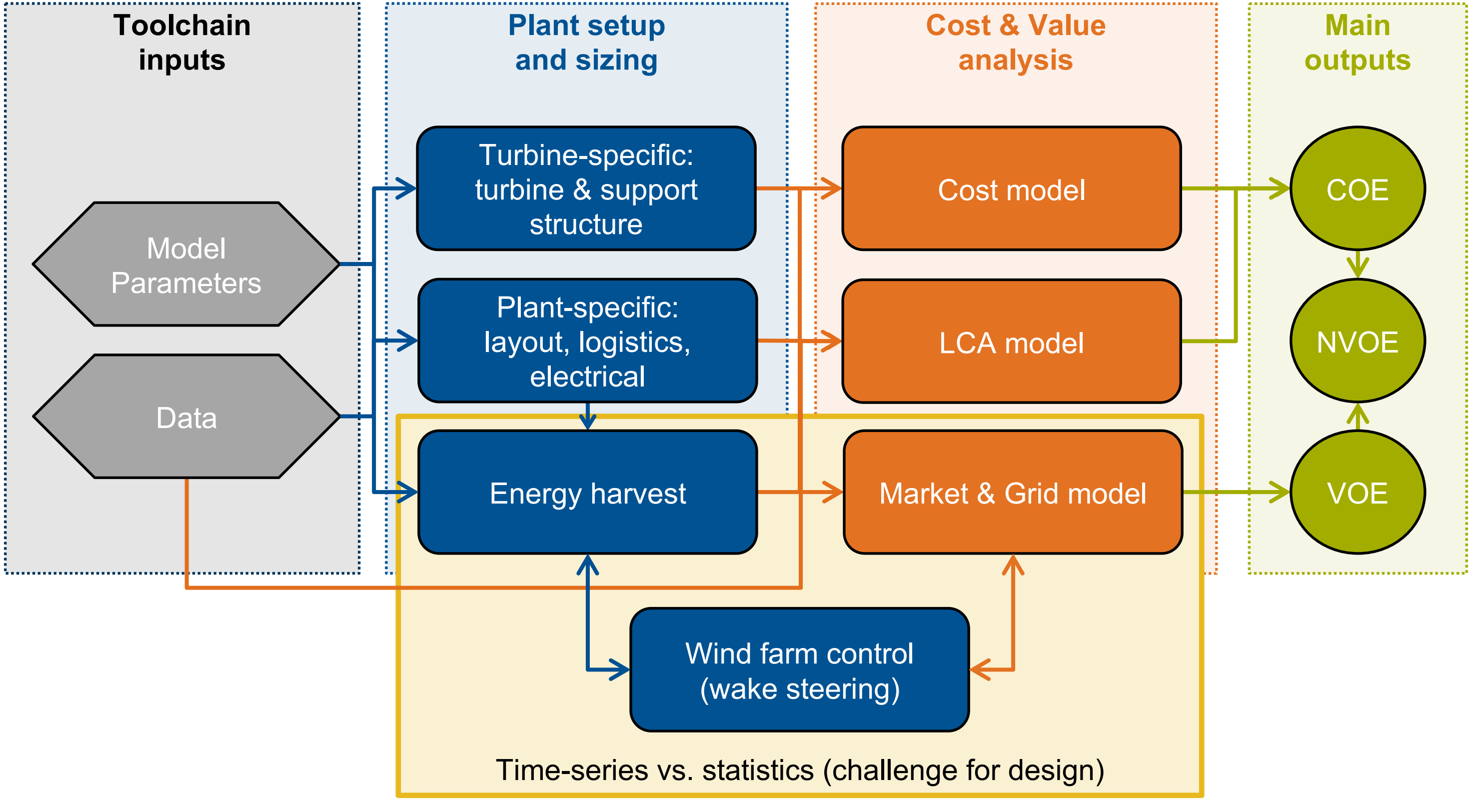
Main outputs



- Regression of spot market price and grid greenhouse gas emissions with wind speed
- Integration with plant power curve
- Ongoing research: ANN for time-series prediction based on system states (→ DeepWind conference)

- > 200 model parameters to approximate case study
- Cradle-to-grave analysis for all components
- Result breakdown per life stage, component, and material

Method (ongoing research)



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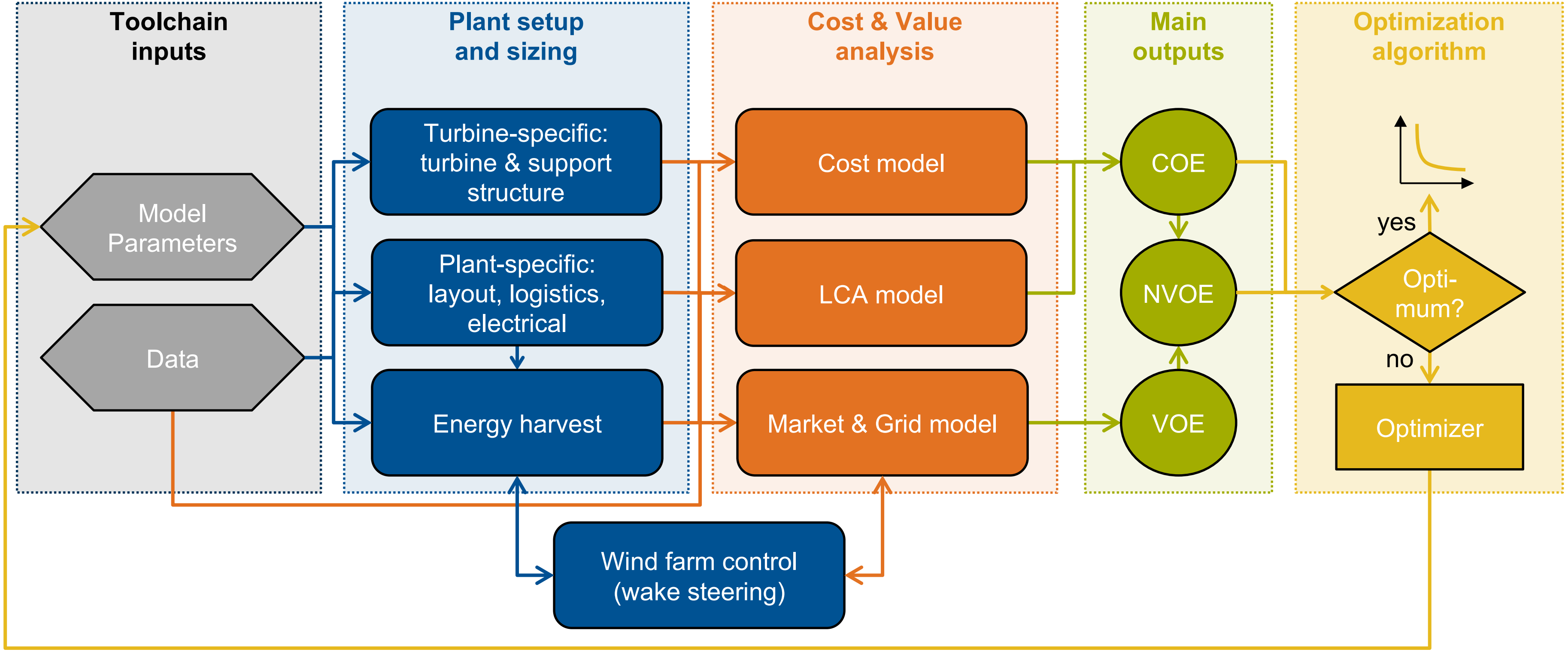
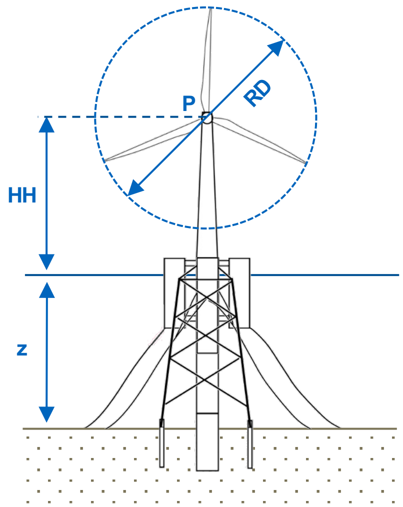
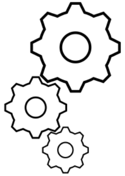


Scope

Life phases:
1. Material extraction
2. Manufacturing
3. Transport to port
4. Installation
5. O&M
6. Decommissioning
7. End-of-Life

Mass breakdown
up to **33 materials**





Powertrain
- Direct drive
- 2S Medium Speed
- 3S High Speed

Floating
- Semisubmersible
- Spar

Fixed-bottom
- Monopile
- Jacket

Scope

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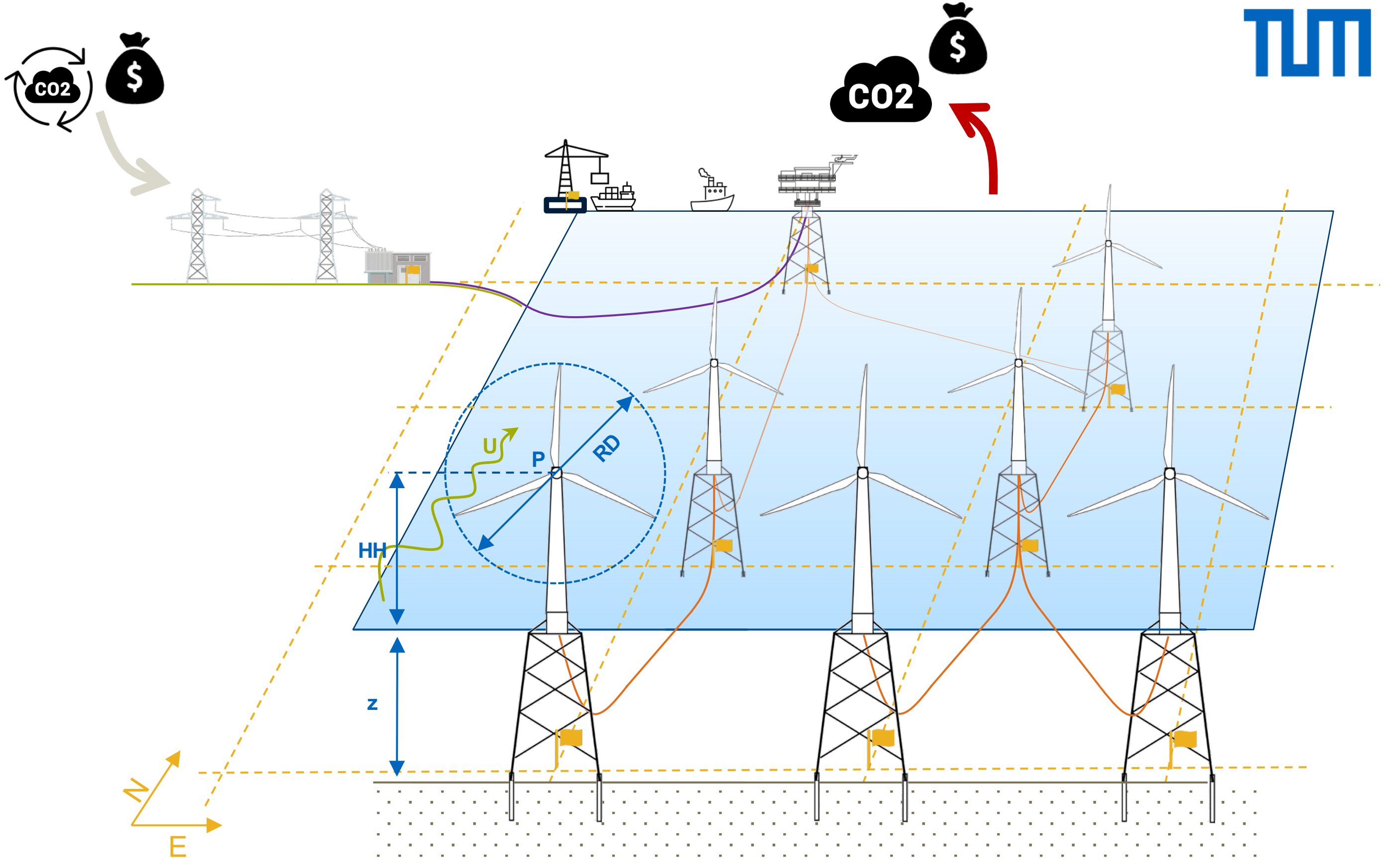
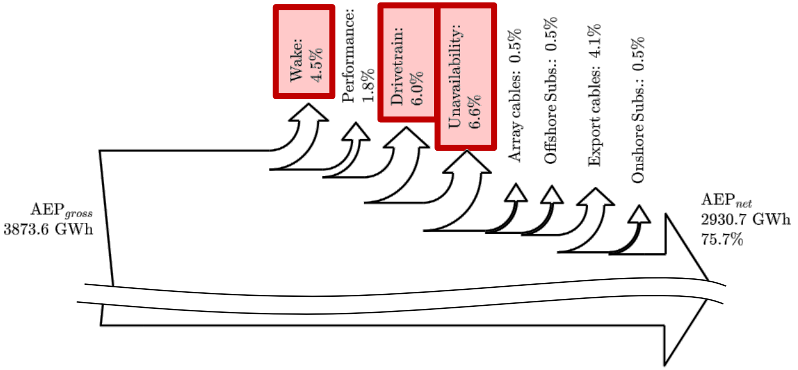


Case study

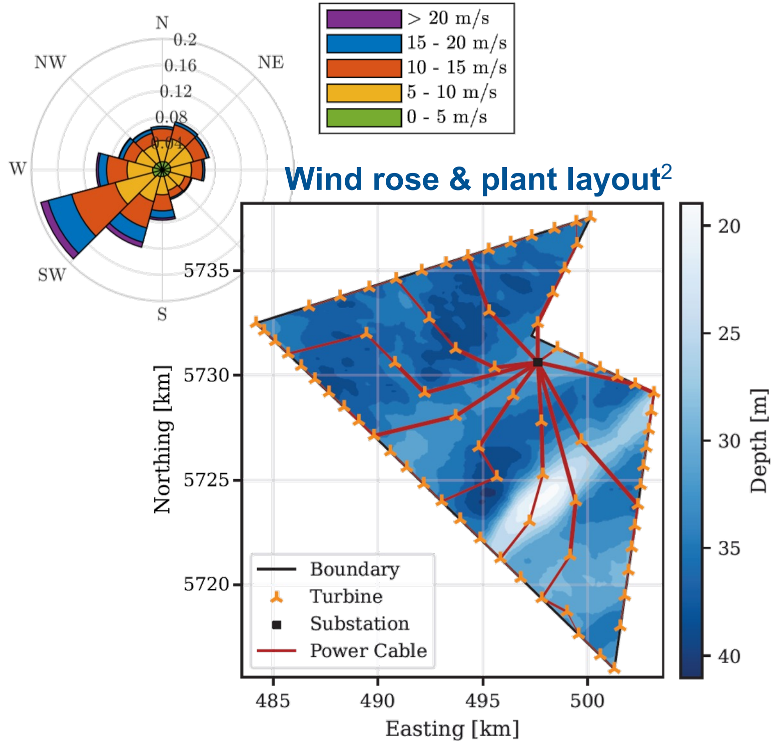
IEA 740-10-MW Reference Offshore Wind Plants

- First IEA Wind Reference Wind Plants
- Located in Dutch-Belgian farm cluster 40 km from shore
- 74 x IEA-10MW Turbines
- Two optimized layouts (regular / irregular) for max. AEP
- Data + report publicly available (Task 55 Github / NREL rep.)

AEP analysis[1]



Wind rose & plant layout[2]



[1]Kainz et al (2024): J. Phys.: Conf. Ser. 2767 082005
[2] Kainz et al (2024): "The IEA Wind 740-10-MW Reference Offshore Wind Plants", NREL Technical Report

Case study

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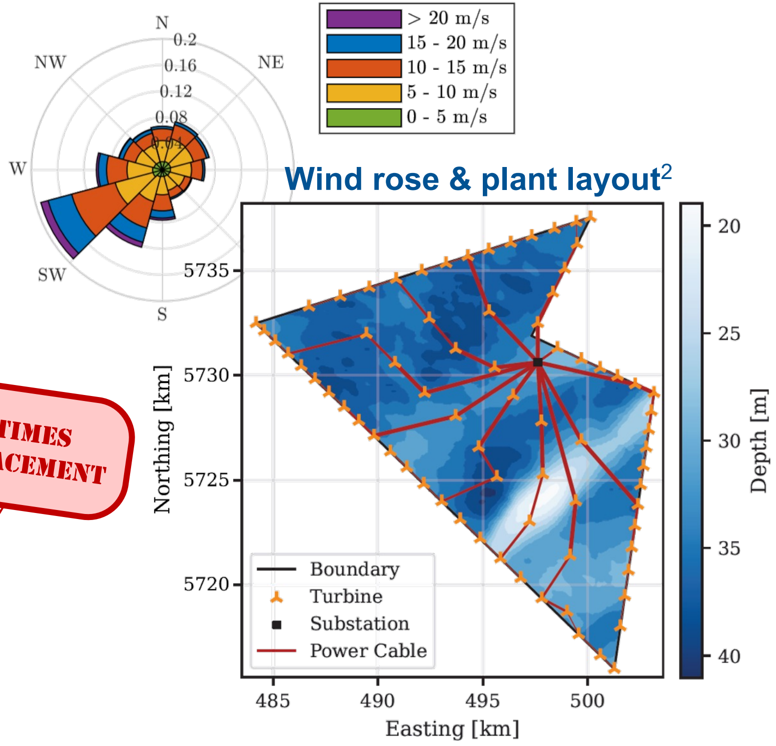
	Economic perspective[1]		Environmental Perspective[1]	
	€/MWh		kgCO2eq /MWh	
Cost	$COE_€$	93.1	COE_{CO2}	16.9
Value	$VOE_€$	166.0	VOE_{CO2}	506.1
Net value	$NVOE_€$	72.9	$NVOE_{CO2}$	489.2

CASE OF HIGH ECONOMIC VIABILITY

30 TIMES DISPLACEMENT

Wind rose & plant layout[2]



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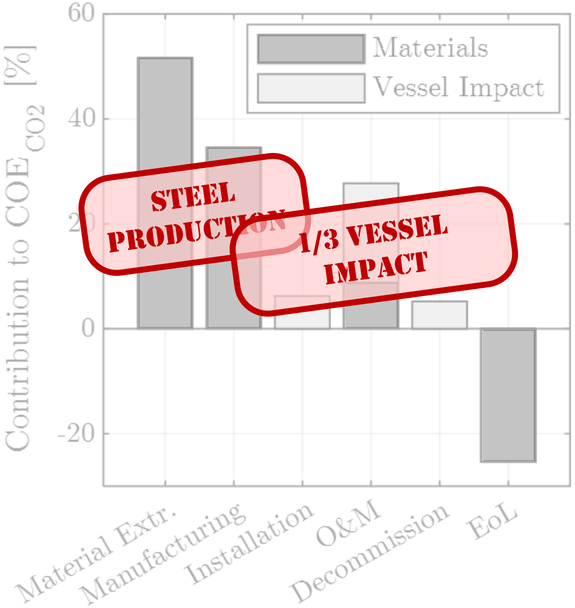
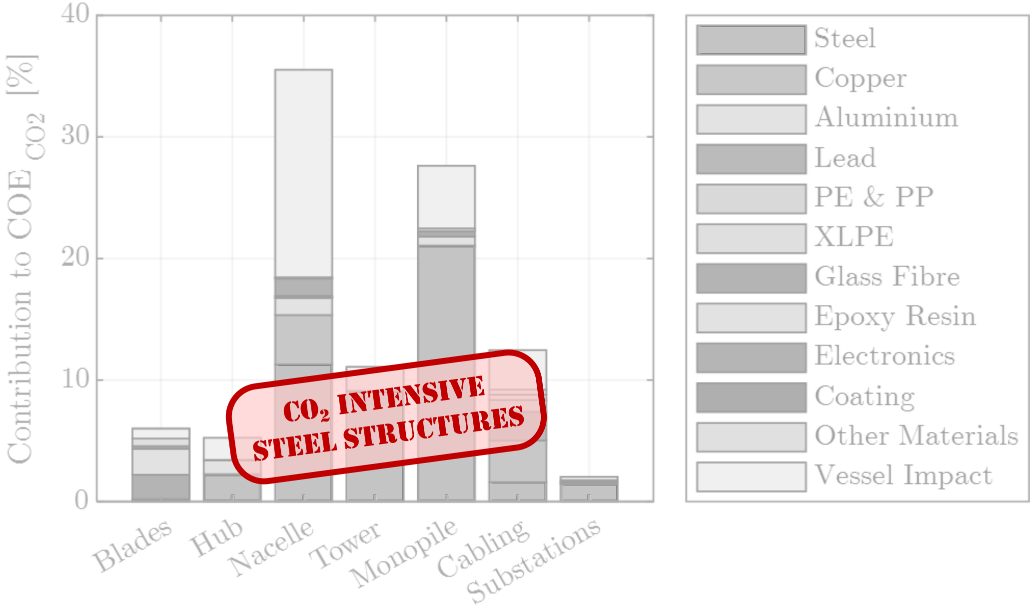
Case study

Baseline Results: COE_{CO2}

Breakdown by life phases[1]



Breakdown by components[1]



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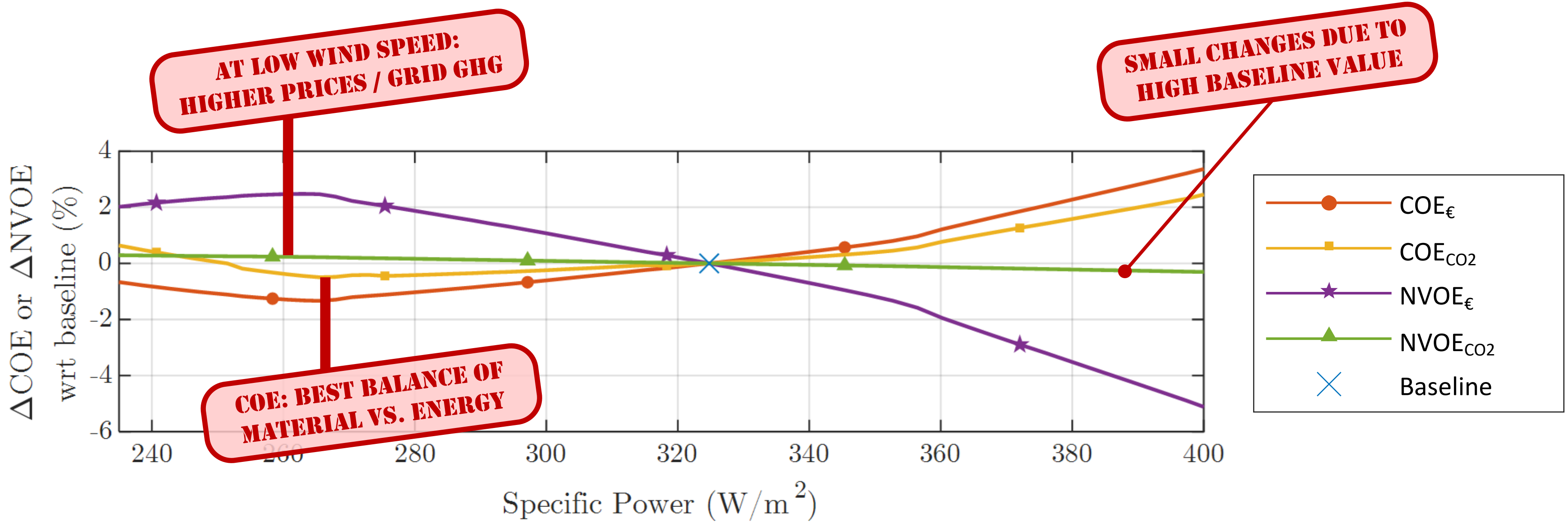
Case study

Technological Choices: Specific Power[1]

Varying rotor diameter while freezing rated power



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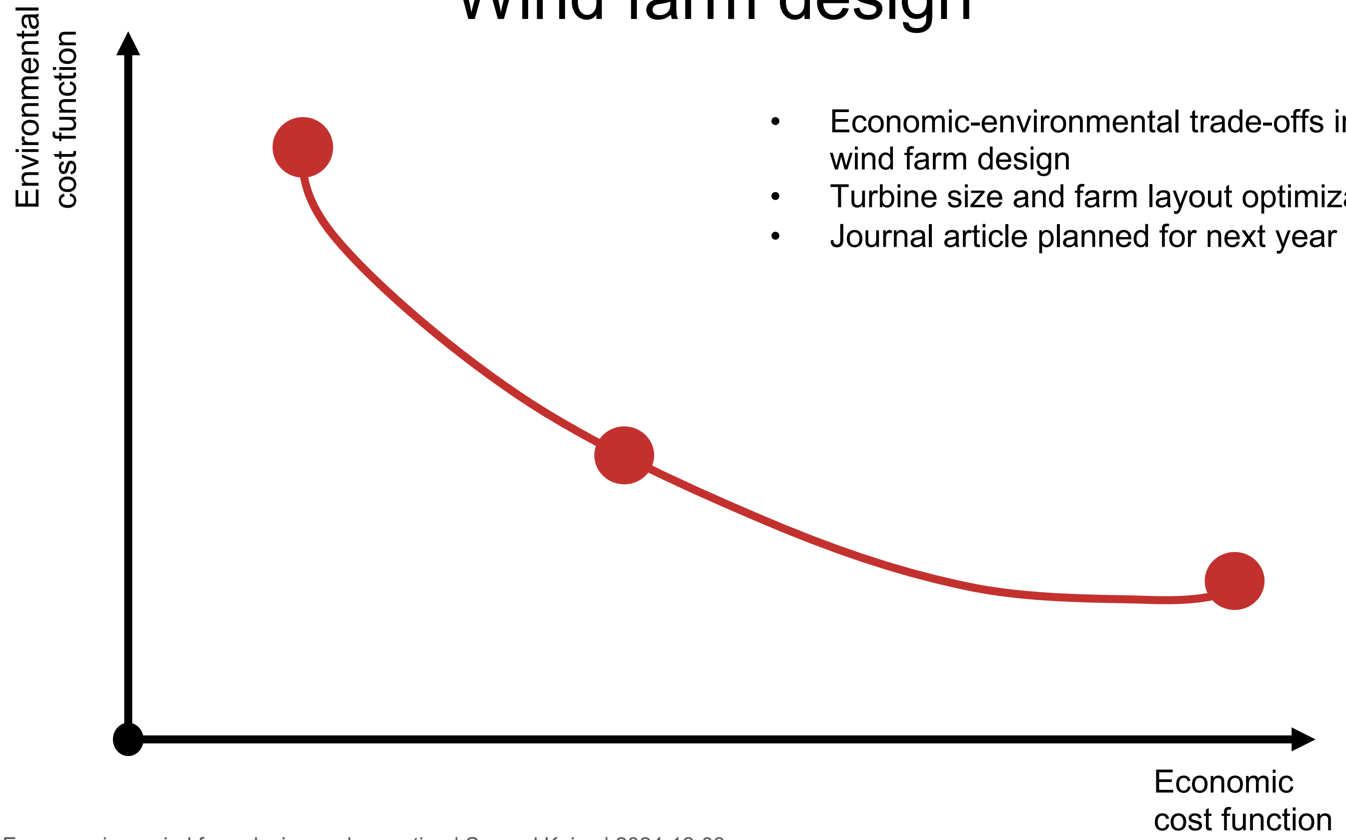
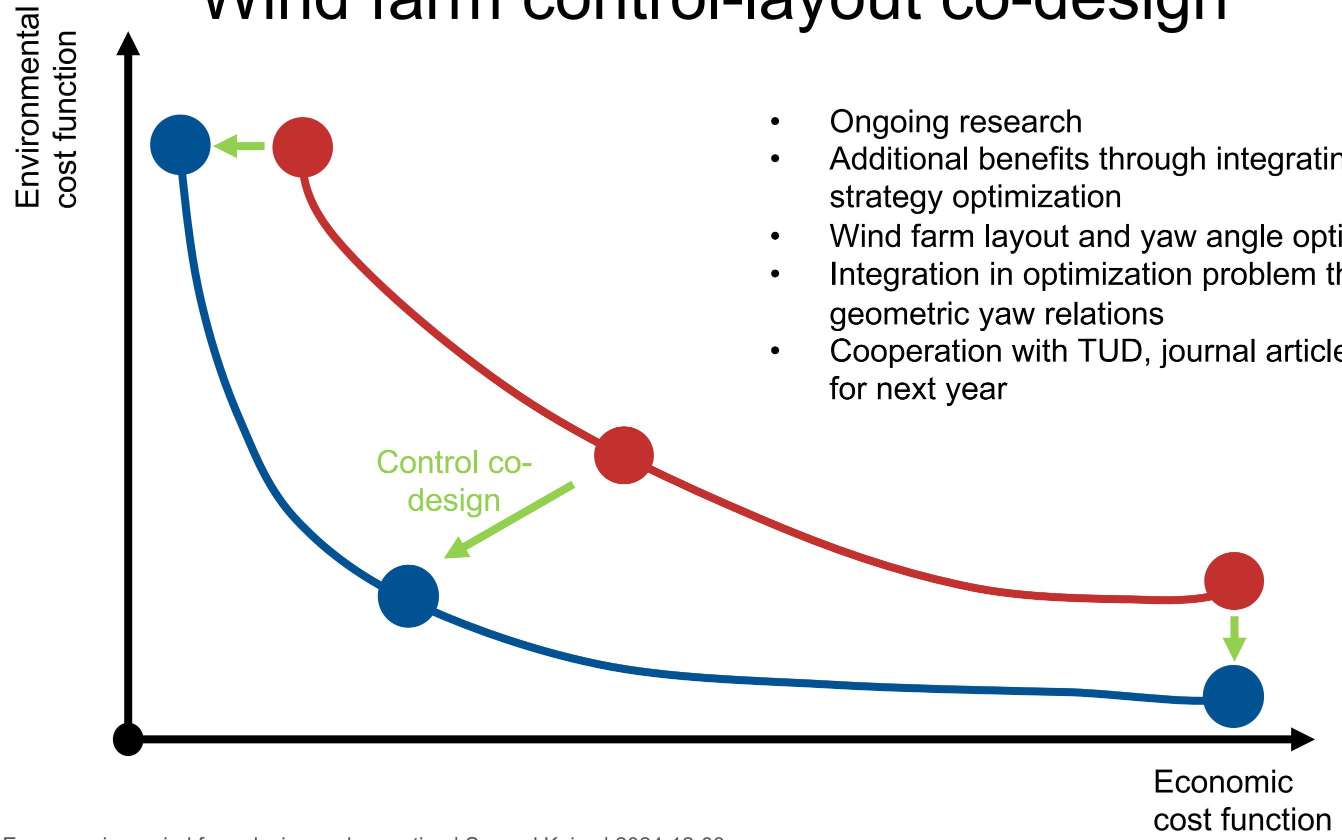
Ongoing research

Wind farm design



- Economic-environmental trade-offs in wind farm design
- Turbine size and farm layout optimization
- Journal article planned for next year

Wind farm control-layout co-design



- Ongoing research
- Additional benefits through integrating control strategy optimization
- Wind farm layout and yaw angle optimization
- Integration in optimization problem through geometric yaw relations
- Cooperation with TUD, journal article planned for next year

Conclusion

Key points:

- Combined economic-environmental assessment and design of offshore wind plants
- Effective mitigation of climate change while ensuring profitability & (future) tender requirement
- Detect similarities and disparities in drivers, identify possible trade-offs
- Structural steel and vessel fuel drive carbon footprint
- 30 times more emissions are displaced in the grid than caused by the wind farm
- Low specific power for value maximization

Ongoing and future work:

- Environmental-economic trade-offs in wind farm design optimization
- Environmental-aware wind farm control strategy optimization
- Control-layout co-design optimization

Thank you for your attention!

Let's discuss…

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