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Economic feasibility study for continued operation of German offshore wind farms

Julia Walgern, David Baumgärtner, Johannes Fricke, Niklas Requate, Martin Dörenkämper, Tobias Meyer, Lukas Vollmer

Introduction and motivation

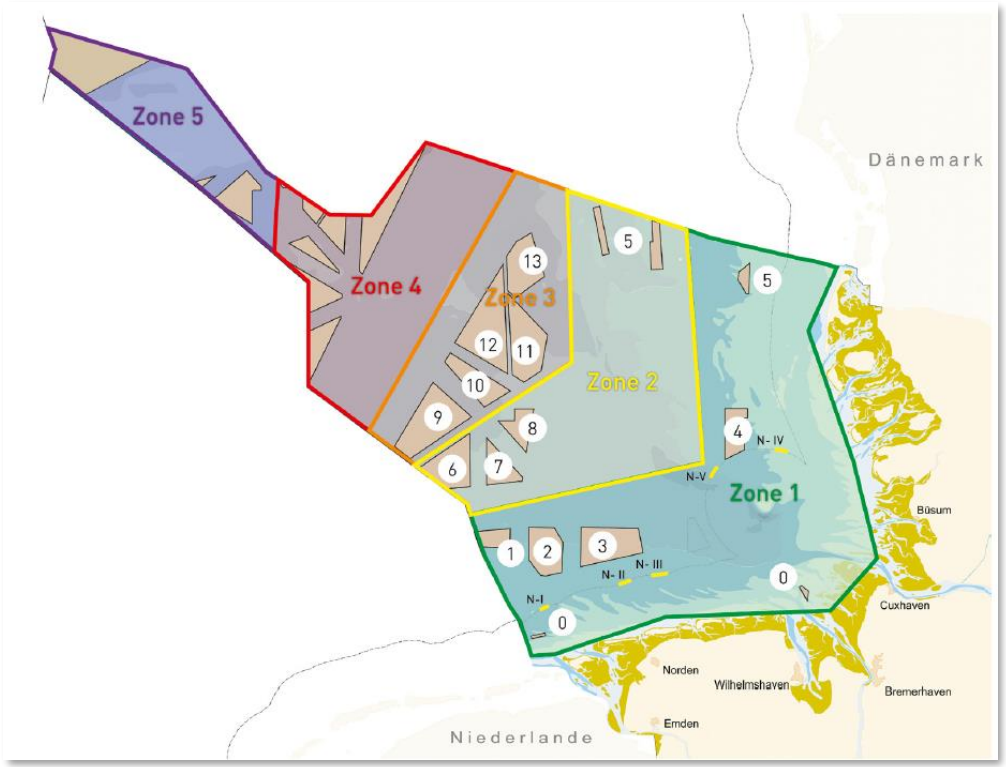
Consultancy work for the Federal Maritime and Hydrographic Agency (BSH)

Accelerated expansion of offshore wind energy in Germany – Newest amendment to the Wind Energy at Sea Act (WindSeeG, July 2022)

- Rated capacity of at least 30 GW installed by 2030
- Rated capacity of at least 40 GW installed by 2035
- Rated capacity of at least 70 GW installed by 2045
- Current status: 1537 offshore wind turbines (WTs) (~ 8 GW) installed

Fraunhofer IWES was commissioned by the BSH for "Further Development of the Framework Conditions for the Planning of Offshore Wind Turbines and Grid Connection Systems"

- How to allocate future offshore wind farm (OWF) capacities smartly?
- Is continued operation of German OWFs economically viable?



(Source: Federal Maritime and Hydrographic Agency)

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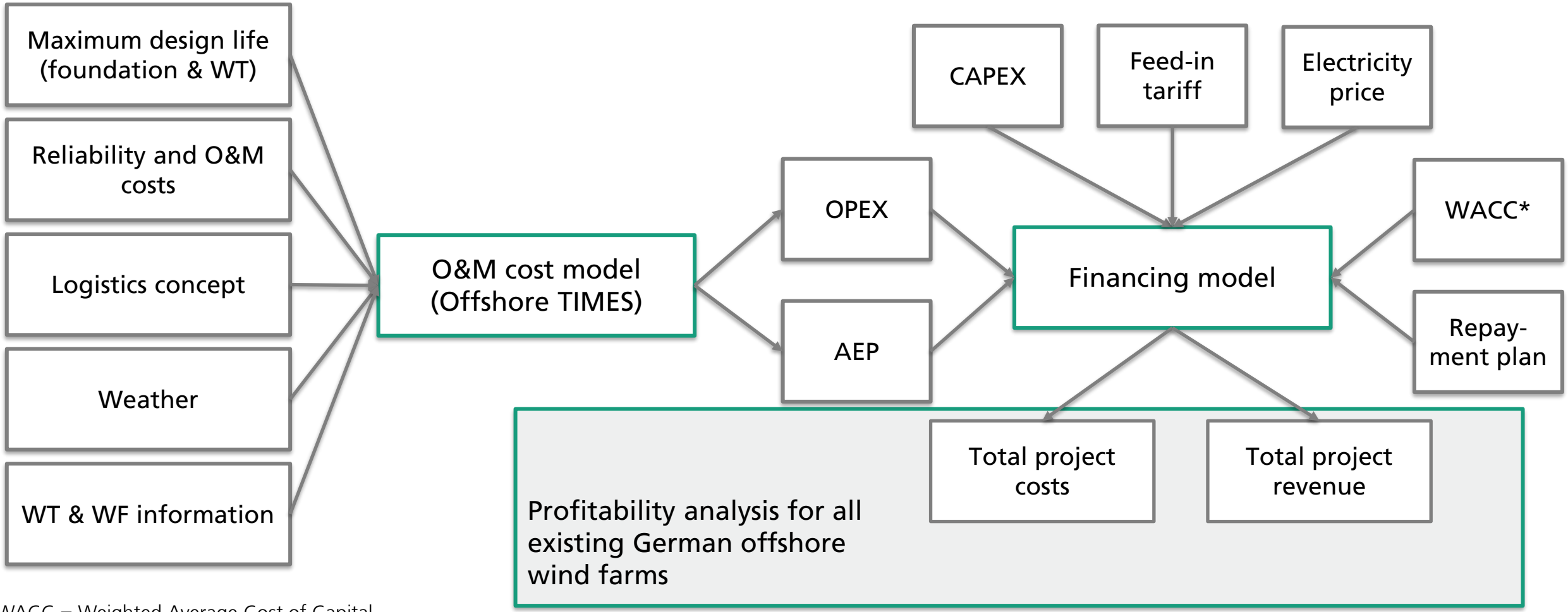
Operating time of offshore wind farms

Economic feasibility analysis – inputs and workflow



*WACC = Weighted Average Cost of Capital

Operating time of offshore wind farms

Workflow

Which operating time can be expected for existing German OWFs?

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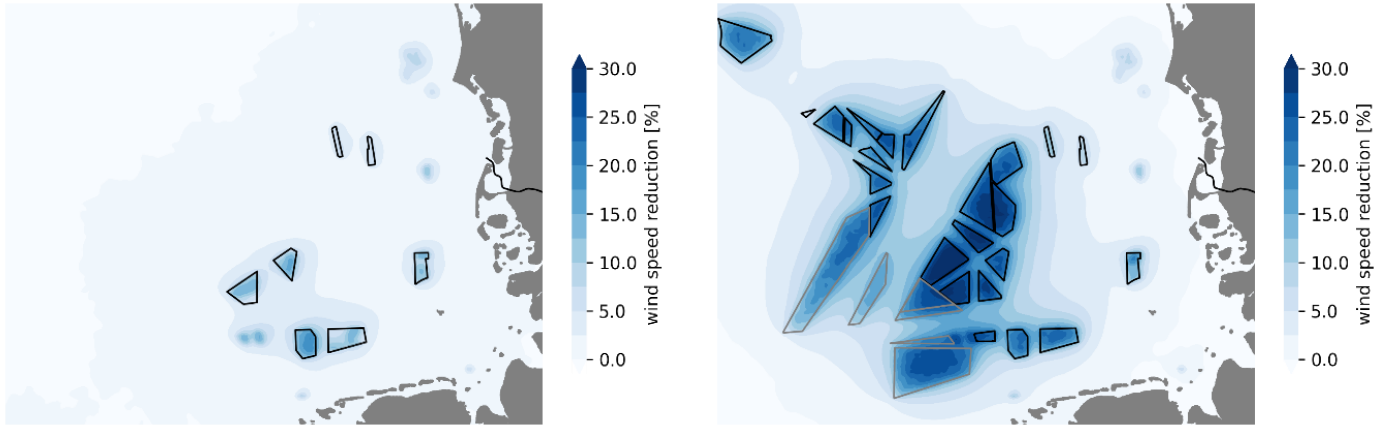
Future yield potential and wake effects

Approach

Considering two states of offshore wind deployment in Germany

- Simulations conducted with WRF* model for estimating the energy yield and the influence of the WFs on the wind field
- Wake losses calculated for these two states of deployment relative to a gross production estimate based on FOXES** calculations
- Based on deployment scenarios of the current Site Development Plan, yearly wake losses per WF estimated



Simulated mean wind speed reduction in the German Bight under current WF deployment (left) and for the future scenario of deployment (right)

* WRF = Weather Research and Forecasting model (Skamarock et al., 2017)

** FOXES = Farm optimization and extended yield evaluation software (Fraunhofer IWES)

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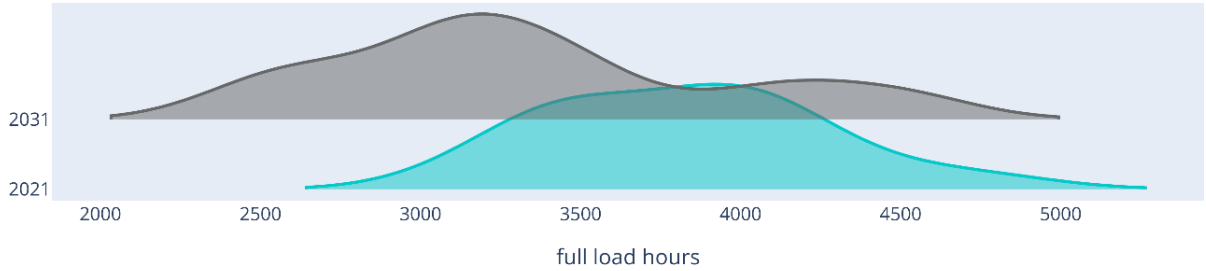
Future yield potential and wake effects

Input for the economic feasibility study

Future yield of most existing German OWFs will decrease

- In 2022: wake losses of approx. 7%-31.5%
- In 2031: wake losses of up to 50%
- Strongly varying effects: some existing WFs only slightly affected by expansion, other areas will see doubling of wake effects



Distribution of mean long term full load hours of analysed OWFs (assuming full availability) in the two simulated expansion scenarios

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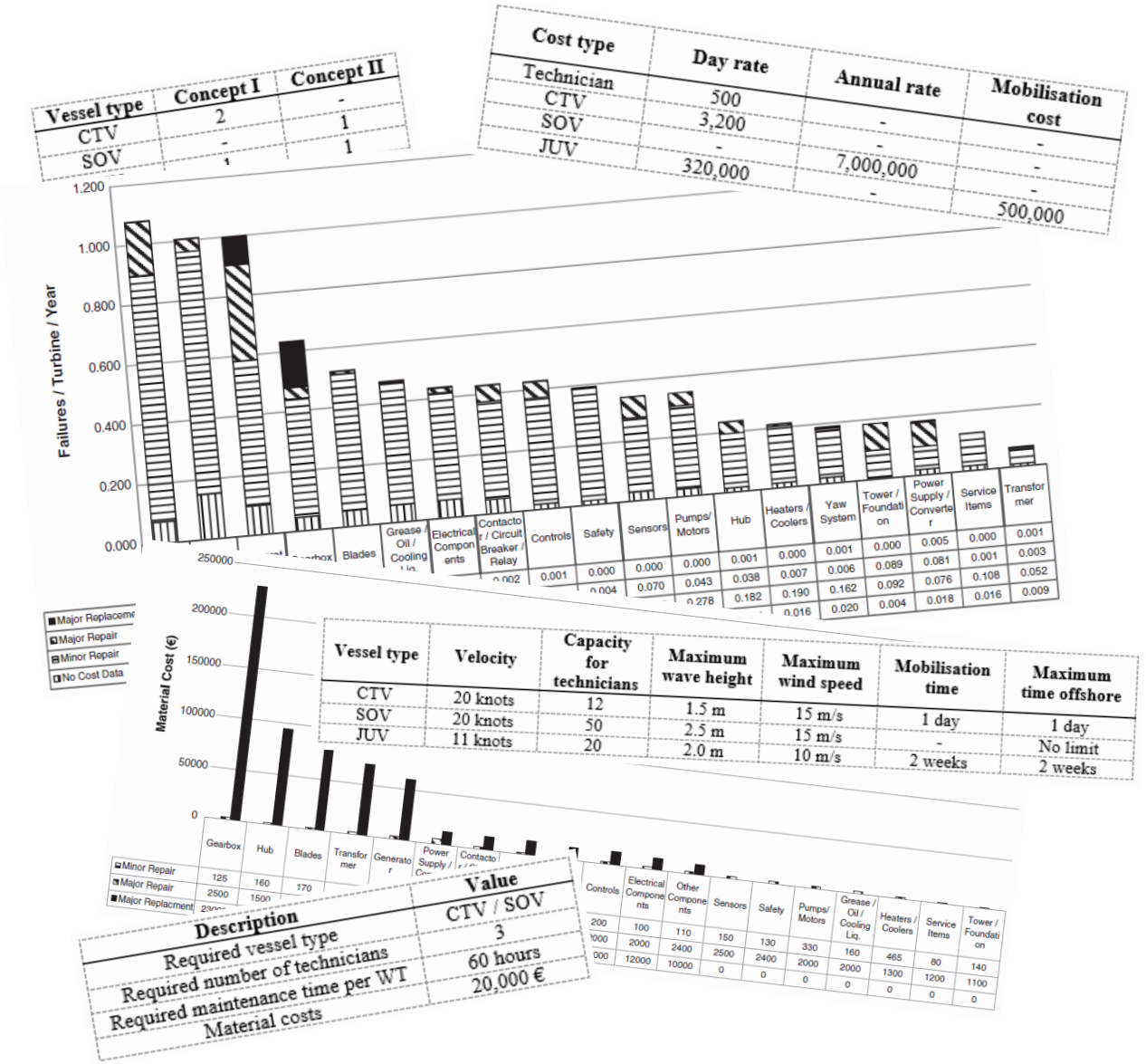
OPEX and CAPEX

Determination of required input parameters

Different publications used as basis for required input parameters. Any inputs discussed with several OWF operators for verification and, where necessary, adaption.

- Modelling of corrective maintenance based on findings of a field data study for offshore WTs by Carroll et al. (2016)
- Modelling of annual maintenance based on publication by Bak et al. (2017)
- Basic assumptions for CAPEX and WACC based on publication by BVGA, The Crown Estate and ORE Catapult (2019)



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Economic feasibility analysis

Evaluation and conclusions

Approach

- Each existing OWF is simulated with Offshore TIMES and a profitability analysis is carried out
- Considering wake losses and remuneration models, an annual turnover is determined which is compared with the annual costs

Fundamental observations

- Investment costs can be repaid within the available Renewable Energies Act (EEG) subsidies
- After guaranteed remuneration according to the EEG, profitability depends heavily on electricity market price
- Further impact factors: Reliability of the WT and its components, the logistic concept, size of the OWF and distance to shore

Year	Residual debt	Interest	Repayment	Annual turnover	OPEX	Profit	Repayment rate
1	900,000,000.00 €	54,000,000.00 €	172,454,685.36 €	210,358,145.42 €	37,903,460.05 €	- €	1
2	781,545,314.64 €	46,892,718.88 €	150,358,277.51 €	188,194,885.92 €	37,836,608.41 €	- €	1
3	678,079,756.01 €	40,684,785.36 €	161,197,899.39 €	198,048,614.18 €	36,850,714.79 €	- €	1
4	557,566,641.97 €	33,453,998.52 €	161,926,226.58 €	197,003,603.04 €	35,077,376.46 €	- €	1
5	429,094,413.91 €	25,745,664.83 €	169,797,405.78 €	204,327,478.84 €	34,530,073.06 €	- €	1
6	285,042,672.96 €	17,102,560.38 €	164,569,078.95 €	198,768,115.55 €	34,199,036.60 €	- €	1
7	137,576,154.40 €	8,254,569.26 €	145,830,723.66 €	188,940,444.94 €	35,632,455.64 €	7,477,265.64 €	1
8	- €	- €	- €	148,273,636.22 €	33,711,574.65 €	114,562,061.58 €	1
9	- €	- €	- €	55,307,511.94 €	34,257,765.74 €	21,049,746.20 €	1
10	- €	- €	- €	50,417,688.24 €	34,283,243.17 €	16,134,445.07 €	1
11	- €	- €	- €	48,790,173.23 €	34,602,182.80 €	14,187,990.43 €	1
12	- €	- €	- €	52,878,542.15 €	34,332,290.56 €	18,546,251.60 €	1
13	- €	- €	- €	53,160,808.23 €	34,304,990.10 €	18,855,818.13 €	1
14	- €	- €	- €	56,085,414.94 €	35,488,610.37 €	20,596,804.56 €	1
15	- €	- €	- €	54,368,305.40 €	38,073,884.71 €	16,294,420.69 €	1
16	- €	- €	- €	77,708,711.99 €	36,015,055.20 €	41,693,656.79 €	1
17	- €	- €	- €	66,847,944.07 €	33,170,834.01 €	33,677,110.06 €	1
18	- €	- €	- €	69,814,250.29 €	33,900,104.37 €	35,914,145.92 €	1
19	- €	- €	- €	62,422,842.37 €	34,916,114.99 €	27,506,727.38 €	1
20	- €	- €	- €	58,372,840.84 €	36,463,741.82 €	21,909,099.02 €	1
21	- €	- €	- €	58,258,644.32 €	37,186,939.27 €	21,071,705.05 €	1
22	- €	- €	- €	64,552,934.40 €	37,542,948.49 €	27,009,985.91 €	1
23	- €	- €	- €	66,289,594.96 €	35,388,369.10 €	30,901,225.87 €	1
24	- €	- €	- €	78,128,808.61 €	35,753,164.22 €	42,375,644.40 €	1
25	- €	- €	- €	75,936,206.43 €	34,771,955.61 €	41,164,250.81 €	1

Exemplary and anonymised evaluation with normalised values

Economic feasibility analysis

Conclusion and outlook

Conclusions

- Operating life of existing OWFs depends primarily on economic viability and thus on the expected electricity price
- Technical lifetime of foundations and WTs is not a strong limiting factor for continued operation of existing German OWFs
- Probably most OWF operators will not only strive for 25 years of operation, but also for up to 10 years of continued operation according to WindSeeG

Outlook

- Results highly depend on input:
  - More sophisticated reliability models required to better understand yearly O&M costs
  - Adaption of Offshore TIMES for considering newest logistic concepts

References
(1/2)

- Press and Information Office of the Federal Government, "Accelerated expansion - More wind energy at sea," 6 April 2022. [Online]. Available: https://www.bundesregierung.de/breg-en/issues/offshore-wind-energy-act-2024112.
- WindSeeG, 2016. *Gesetz zur Entwicklung und Förderung der Windenergie auf See (Windenergie-auf-See-Gesetz).* [Online]. Available: https://www.gesetze-im-internet.de/windseeg/WindSeeG.pdf.
- *ZGzÄWindSeeG,* 2022. *Zweite Gesetz zur Änderung des Windenergie-auf-See-Gesetzes und anderer Vorschriften*. [Online]. Available: https://www.bgbl.de/xaver/bgbl/text.xav?SID=&tf=xaver.component.Text_0&tocf=&qmf=&hlf=xaver.component.Hitlist_0&bk=bgbl&start=%2F%2F*%5B%40node_id%3D%271034949%27% 5D&skin=pdf&tlevel=2&nohist=1&sinst=00DE2A80.
- Federal Maritime and Hydrographic Agency, *Site Development Plan,* 2022. [Online]. Available: https://www.bsh.de/EN/TOPICS/Offshore/Sectoral_planning/Site_development_plan/site_development_plan_node.html;jsessionid=09CCC842FC9DA15E7D16908385A27DE1.live21304
- M. Wiggert, L. Meyer-Lerbs, G. Wolken-Möhlmann und E. Dietrich, "Offshore TIMES - Offshore Transport, Inspection and Maintenance Software : Abschlussbericht," Fraunhofer-Institut für Windenergiesysteme, Bremerhaven, 2018.
- H. Hersbach, B. Bell, P. Berrisford, S. Hirahara, A. Horányi, J. Muñoz-Sabater, J. Nicolas, C. Peubey, R. Radu, D. Schepers, A. Simmons, C. Soci, S. Abdalla, X. Abellan, G. Balsamo, P. Bechtold, G. Biavati, J. Bidlot und M. Bonavita, "The ERA5 global reanalysis," *Quarterly Journal of the Royal Meteorological Society,* pp. 1999-2049, July 2020.

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References
(2/2)

- W. C. Skamarock, J. B. Klemp, J. Dudhia, D. O. Gill, Z. Liu und J. Berner, “A Description of the Advanced Research WRF Model Version 4”, 2019.
- J. Carroll, A. McDonald und D. McMillan, "Failure rate, repair time and unscheduled O&M cost analysis of offshore wind turbines," Wind Energy 19, pp. 1107-1119, 2016.
- T. Bak, A. Graham, A. Sapronova, M. Florian, J. Dalsgaard Soerensen, T. Knudsen, P. Hou und Z. Chen, "Baseline layout and design of a 0.8 GW reference wind farm in the North Sea," Wind Energies 20, pp. 1665-1683, 2017.
- BVG Associates, “Guide to an offshore wind farm”, 2019. [Online]. Available: https://www.thecrownestate.co.uk/media/2861/guide-to-offshore-wind-farm-2019.pdf
- Energi Data Service, *Elspot Prices*. [Online]. Available: https://www.energidataservice.dk/tso-electricity/Elspotprices
- S. Patzack, P. Svoboda, J. Wilms, G. Gerdes, A. Armeni und R. Borrmann, “Unterstützung zur Aufstellung und Fortschreibung des FEP. Zukünftige Rahmenbedingungen für die Auslegung von Offshore-Windparks und deren Netzanbindungssystemen”. Endbericht., 2020.

Thanks for your attention.
Any questions?

Julia Walgern
Group Manager Technical Reliability
Fraunhofer Institute for Wind Energy Systems IWES

Phone +49 471 14290-549
Julia.Walgern@iwes.fraunhofer.de