Characterising the impact of cold climate atmospheric conditions for offshore turbines through a review of operational data

Winterwind 2022, Skellefteå

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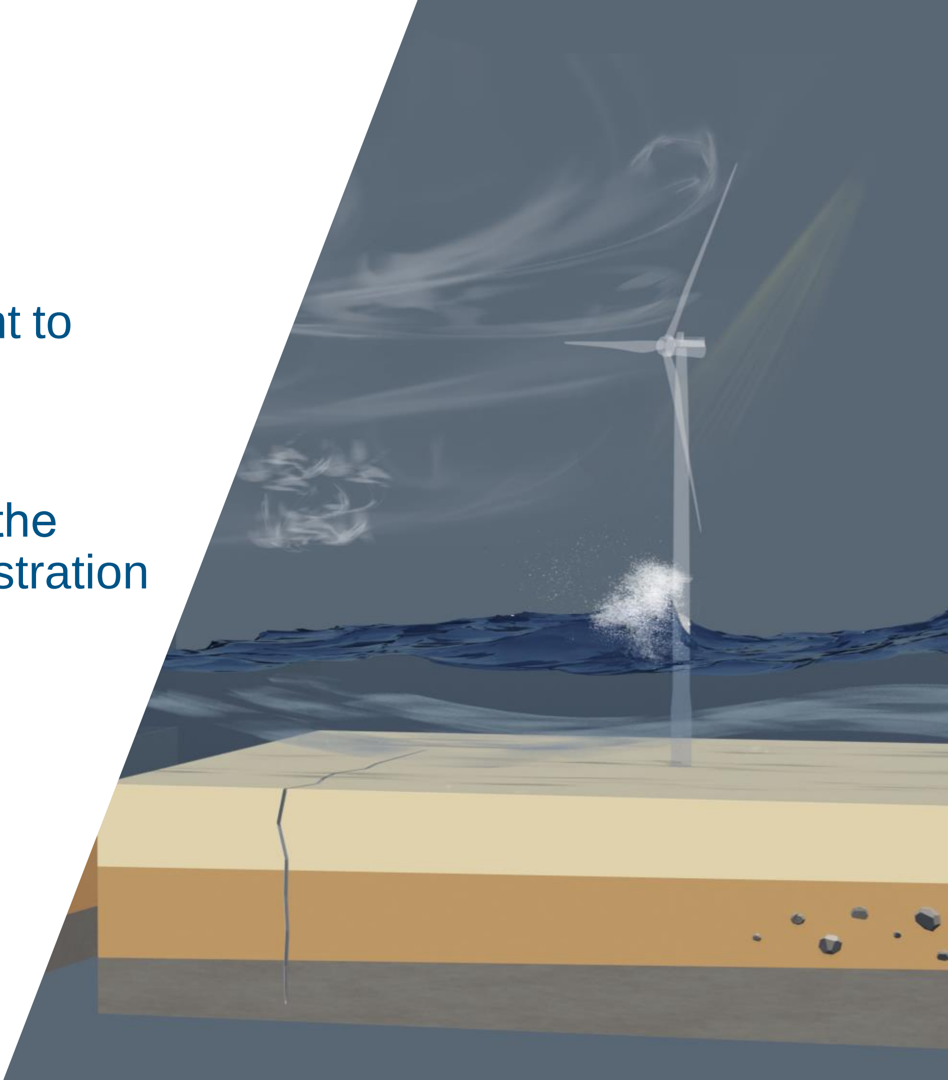
With thanks and acknowledgement also to Jon Collins, Carla Ribeiro (Wood Thilsted)

Agenda

- Why is atmospheric stability important to consider for turbine performance?

- An ‘offshore’ study case: Analysis of the ORE Catapult’s Levenmouth Demonstration Turbine

- Conclusions and recommendations



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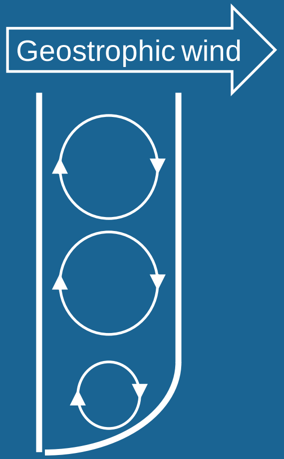
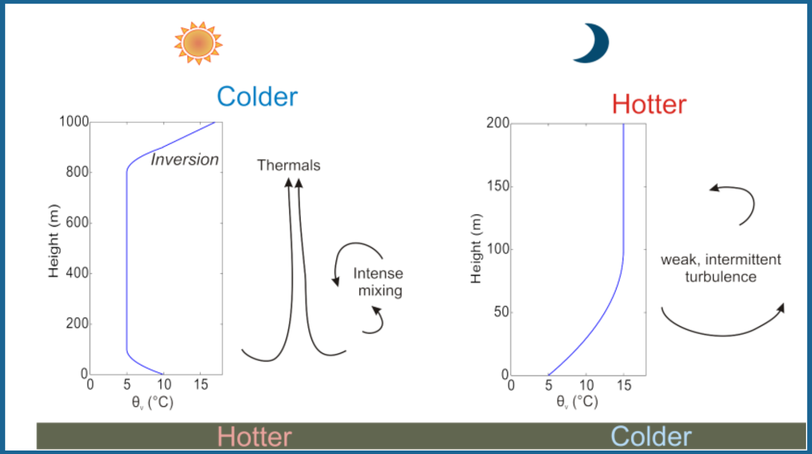
WHY IS ATMOSPHERIC STABILITY IMPORTANT?

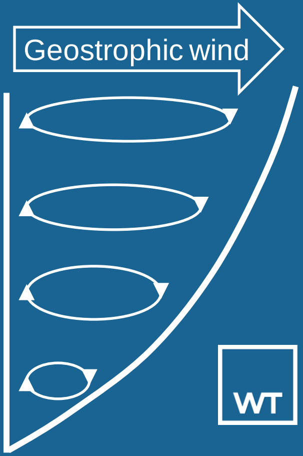
- Atmospheric stability impacts the vertical distribution of momentum (i.e. wind shear and turbulence intensity)
- These have implications for both energy production and design

Unstable

Stable







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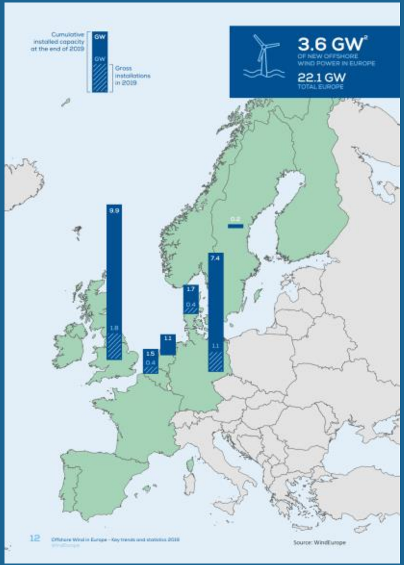
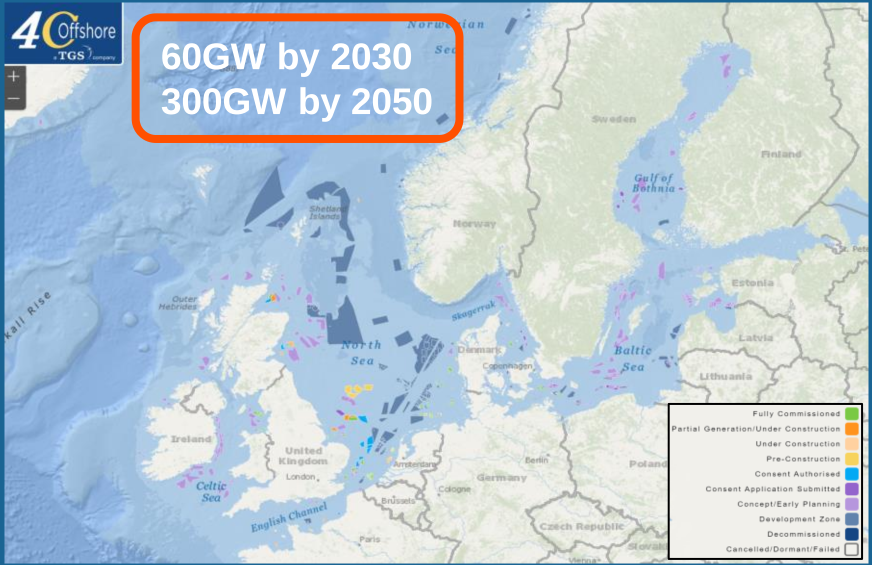
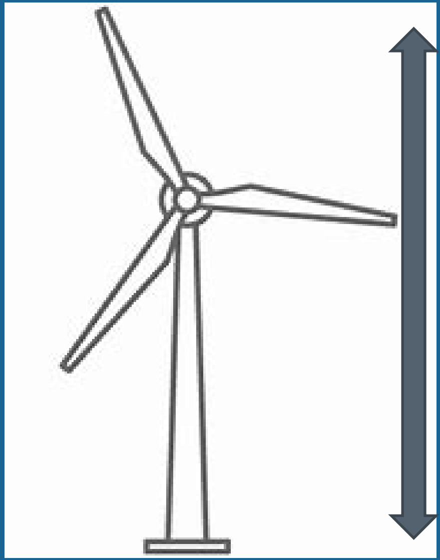
OFFSHORE SPECIFIC CONSIDERATIONS





60GW by 2030
300GW by 2050



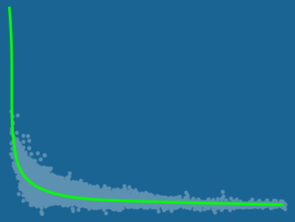
Up to ~300m tip heights

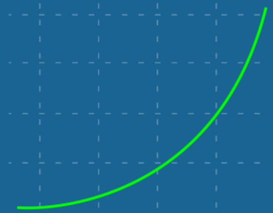
RECAP

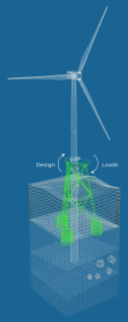
- We will see more offshore wind sites with a greater prevalence of stable atmospheric conditions.
- The increasing size of turbines reaching further into the atmospheric boundary layer also necessitates a greater understanding of complex wind flow events which are likely to impact the rotor at these higher heights.

Better understanding of the wind climate

Better designs and more accurate AEP

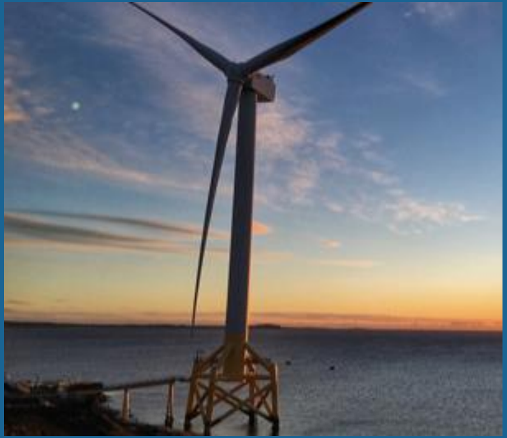






AN OFFSHORE STUDY CASE: THE MOTIVATION

- Impact of cold weather driven atmospheric stability on onshore turbines well researched [1].
- Industry evidence based on nacelle mounted Lidar campaigns suggests that 'off design' low turbulence conditions at offshore wind farms have a negative impact on performance [2].
- The authors seek to further build on this limited evidence to date by performing an analysis of the publicly available Levenmouth Demonstration Test site datasets in Fife, Scotland (credit: Offshore Renewable Energy Catapult)



[1] C Ribeiro, S Cox, S Lindahl, "An investigation into turbine performance under cold weather driven stable atmospheric conditions in Scandinavia", WinterWind 2013 .

[2] F Ettrup Brink, N G Nygaard, "Measurements of the wind turbine induction zone", 21st meeting of the Power Curve Working Groups 2016 .

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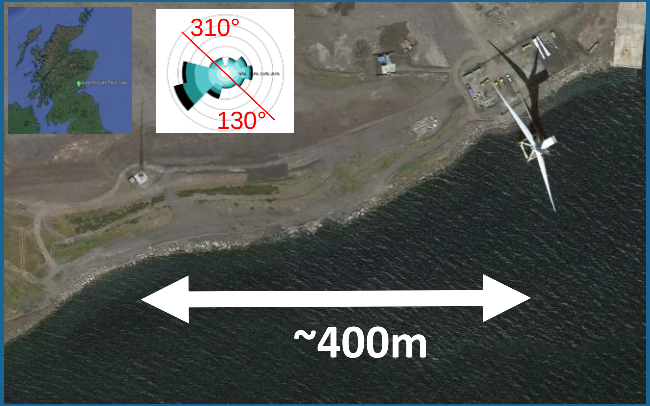
LEVENMOUTH TEST SITE



Temperature

106 m

3 m

Wind speed/dir

110 m

67.5 m

25 m

7MW Samsung turbine, 170m rotor diameter

- Concurrent data from January 2017 (87% valid data coverage)
- Maybe not truly ‘cold climate’, however, a unique combination of robust meteorological measurements and detailed turbine production data

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DATA ANALYSIS

- Met mast data quality checked and wake-affected direction sectors removed from the analysis.
- Turbine data flagged for periods of unavailability, curtailment or sub-optimal performance.
- Reference wind speed data (nacelle anemometer) has been corrected to a standard air density following the IEC standard.
- Mast data has been used to separate the filtered turbine dataset in to stable vs. unstable/neutral conditions.

NOTE: Ideally the non-turbine-affected mast measured wind speed data would have been used to derive the reference power curve as per IEC 61400-12-1:2017. However, the nacelle wind speed was taken to avoid the compounding effect of different speedups between the mast and turbine location for different atmospheric conditions as described in [1].

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CLASSIFYING ATMOSPHERIC STABILITY

- Two approaches considered:
  - Obukhov Length (requires temperature measurements at 2 heights)

Table 1 Definition of stability classes.

Stability Class iC	Description	Condition
-4	extremely unstable	-50m< L < 0m
-3	very unstable	-100m< L < -50m
-2	unstable	-200m< L <-100m
-1	near unstable/neutral	-500m< L <-200m
0	neutral	500m< $\|L\|$
1	near stable/neutral	200m< L < 500m
2	stable	50m< L < 200m
3	very stable	10m< L < 50m
4	extremely stable	0m< L < 50m

  - Wind shear (α) and Turbulence Intensity (TI) profile as proxies (high shear and low TI to represent stable conditions)

$$\frac{\overline{U}(z_1)}{\overline{U}(z_2)} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

$$\mathrm{TI} = \frac{\sigma}{U_{mean}}$$

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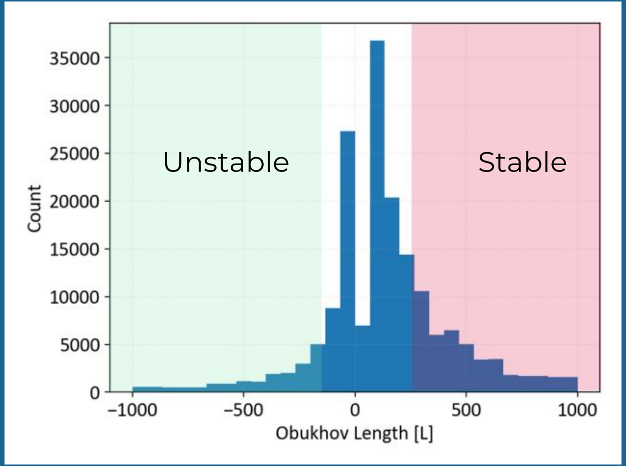
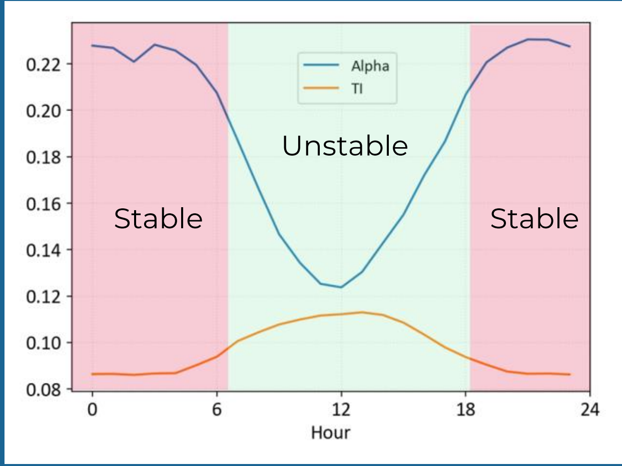
MAST DATA RESULTS

- High frequency of stable atmospheric conditions.
- Results from both approaches support each other.
- Strong diurnal trend, stable conditions occurring during night, typical of coastal location.
- As a result, this site may not be fully representative of a far offshore site and caution should be exercised in extrapolating the results of this study.

Obukhov Length

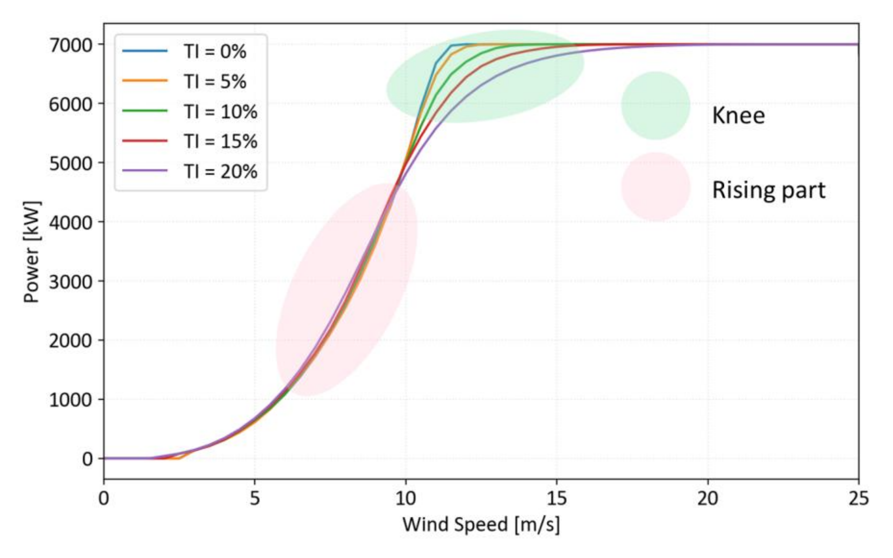


Shear and TI proxies



TURBINE PERFORMANCE IN STABLE CONDITIONS

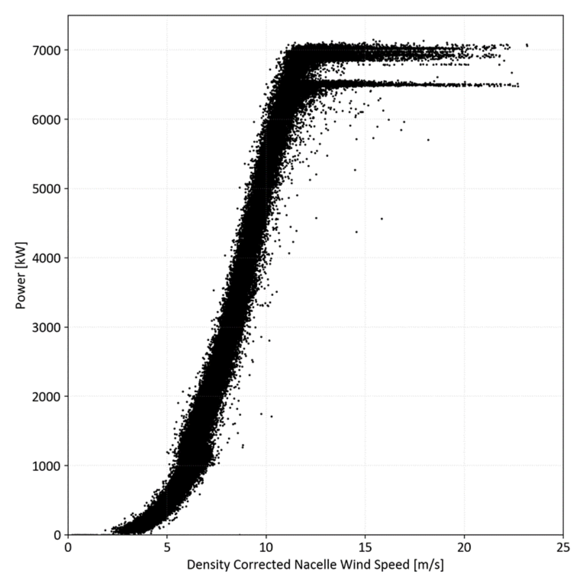
- Theory shows that low turbulence reduces turbine performance in rising part of the power curve, and provides a benefit in the knee of the power curve.
- Offshore turbines are designed for low ambient turbulence intensity – but what about 'off design' low turbulence?



TURBINE DATA

- Two distinct periods of rated power observed in the data.
- The analysis has been split in to these 2 periods.
- For each period, mean power curves representative of stable and neutral/unstable conditions have been derived.

Filtered turbine data



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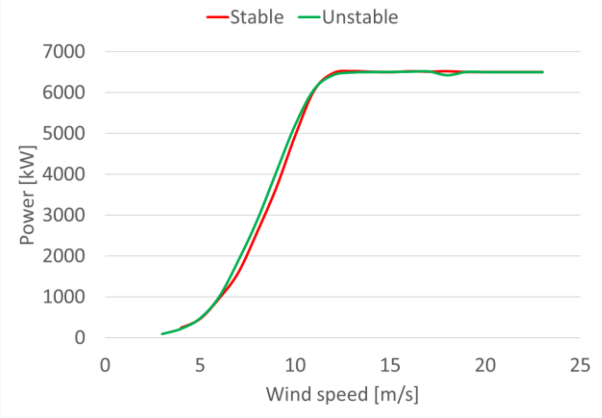
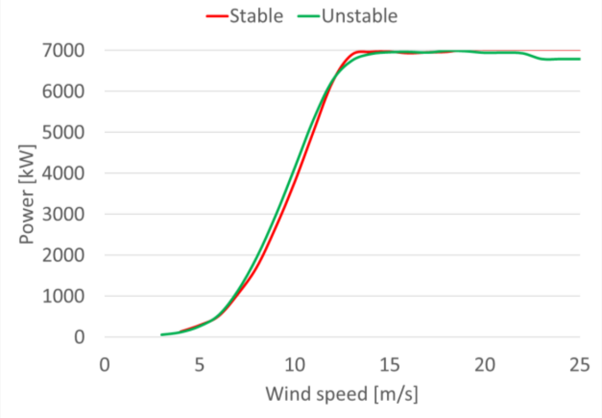
TURBINE DATA RESULTS

- Observations support theory
- Equates to an estimated lower energy production of the order of 2% to 3% during stable conditions compared to average conditions.
- Impact on annual energy production would be less than this.
- Not as significant as typical icing losses experienced in cold climates, but still important to understand!

Period 1



Period 2

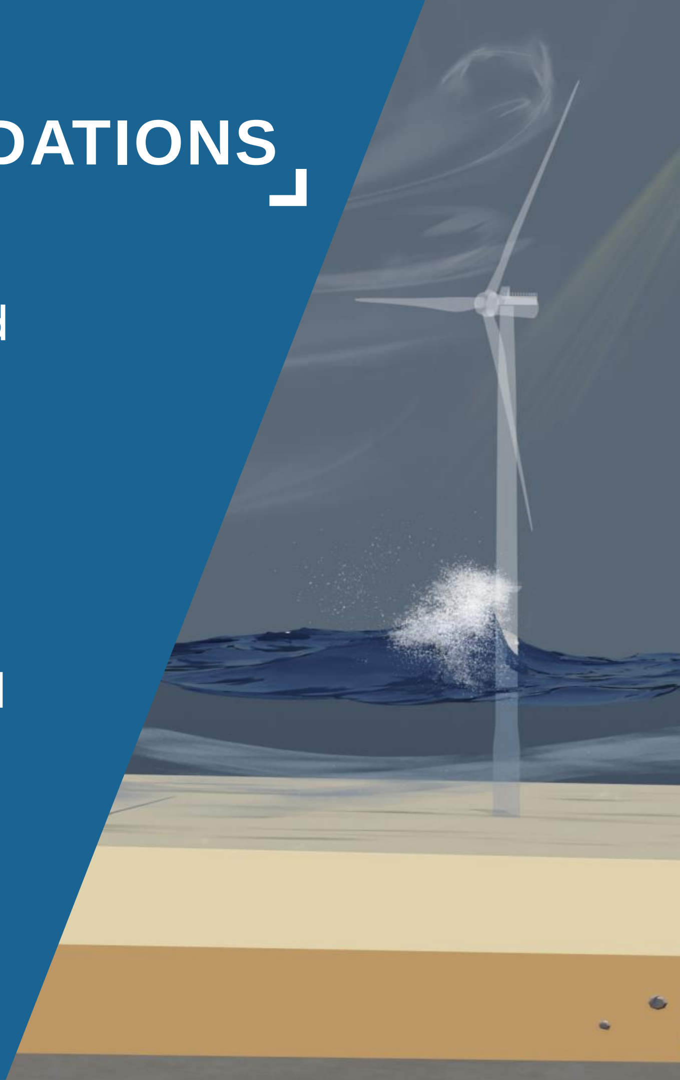


CONCLUSIONS AND RECOMMENDATIONS

- Future offshore wind farms are proposed in areas with an increased prevalence of cold weather driven stable atmospheric conditions.

- Levenmouth study case shows evidence of turbine under-performance during stable conditions – is this being captured in energy yield assessments?

- This effect needs to be better quantified and estimated through adequate site measurements and more representative offshore datasets to expand this analysis.



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