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Offshore Renewable Energy Infrastructure Under Climate Change: A Review of Structural Reliability, Climate Impacts, and Energy Security

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INTRODUCTION

Offshore structures face extreme metocean actions [1,2,3].
Climate change is expected to increase structural stress and failure probability [4,5,6].
Reliable assessment methods are essential for safety and sustainability [7,8].
This study provides a unified review linking climate stressors, structural reliability, and probabilistic safety methods for offshore systems.

METHOD

Systematic review of more than 60 peer-reviewed studies.
Environmental actions include wind, waves, currents, and sea level rise [3,9].
Structural Reliability Analysis (SRA) is based on the limit state function: $g(X) = R - S$ [7,10,11].
R = resistance / S = environmental action effect

RESULTS

Climate variability contributes to uncertainty in environmental actions and failure probability [5,6,12].
Reliability index β is inversely related to probability of failure (POF), indicating structural resilience [7,8].
Offshore wind capacity is projected to grow from 83 GW (2025) to 1,600 GW (2050), based on GWEC and IEA scenarios [13–14].

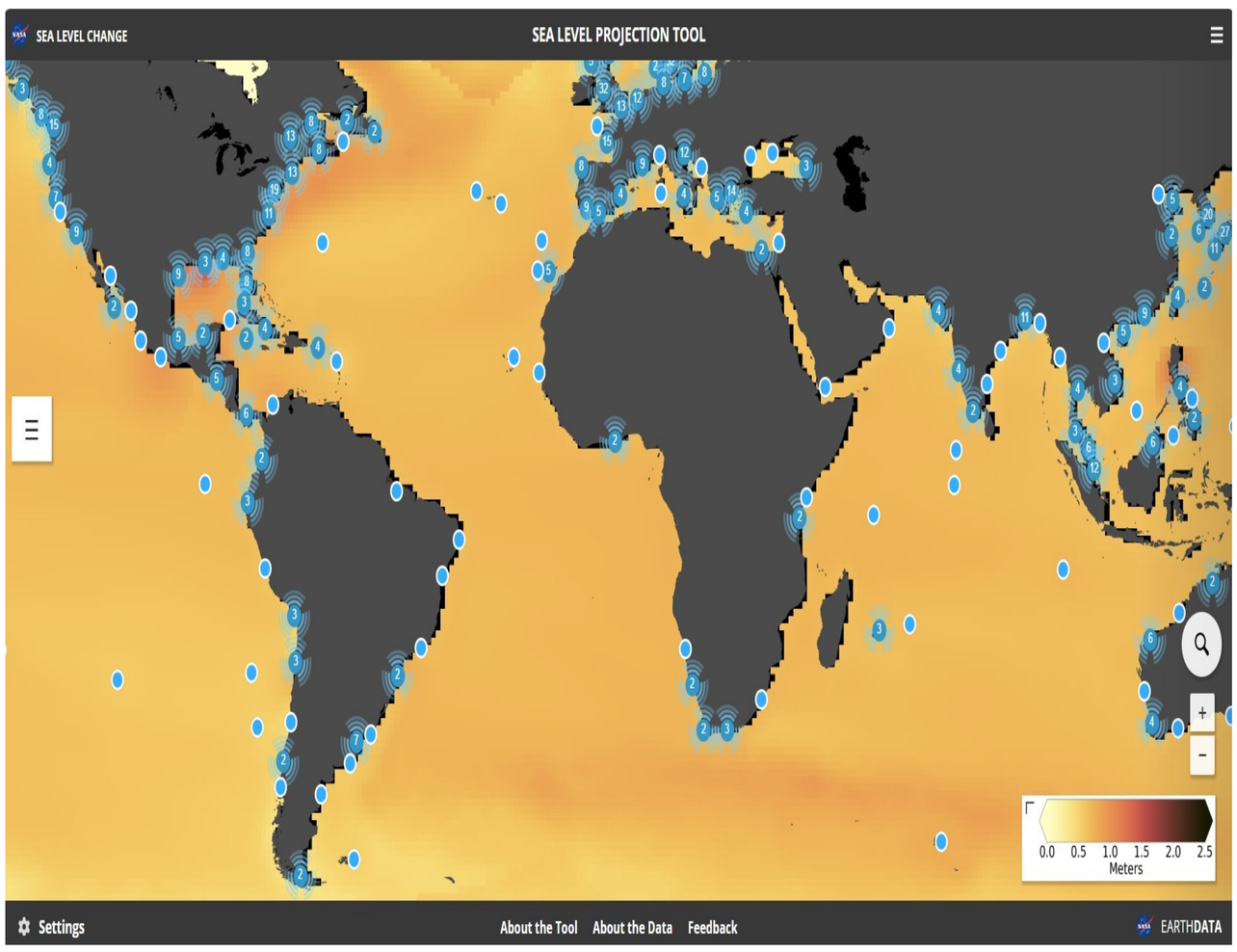

Figure 1. Global mean sea level rise projections under SSP3-7.0 scenario (2020–2100), relative to 1995–2014 baseline (Figure extracted from NASA Sea Level Change Portal [15] and processed by the authors).

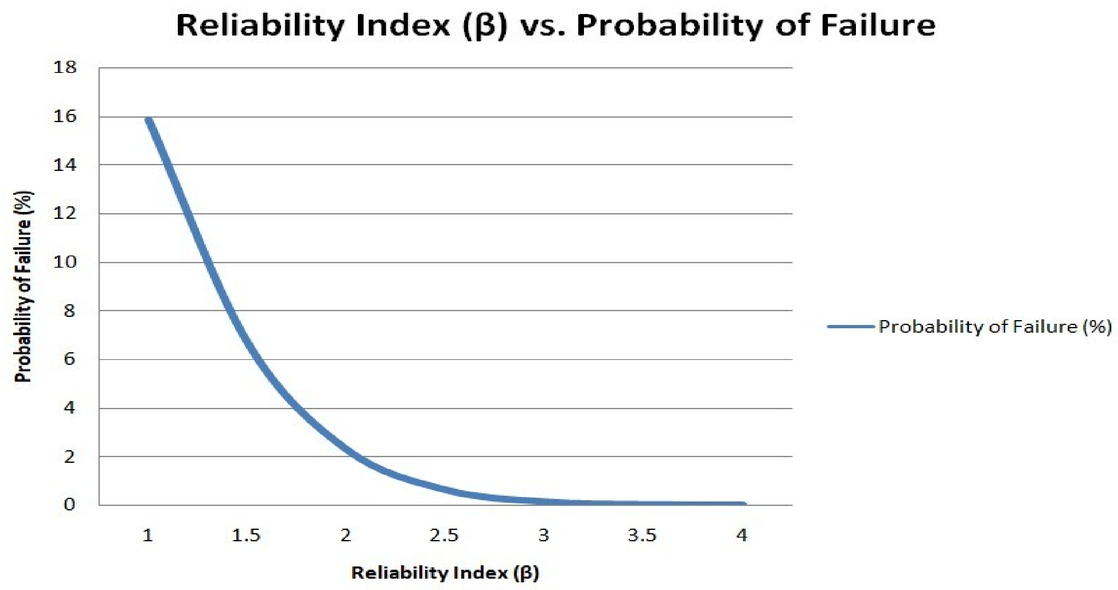

Figure 2. Reliability Index (β) vs. Probability of Failure (%) for offshore structures. The curve illustrates the inverse exponential relationship between structural reliability and failure probability (Figure produced by the authors).

CONCLUSIONS

Offshore structures are highly exposed to climate-induced actions [5,3].
Climate change may increase failure probability and structural uncertainty [5,7].
Probabilistic SRA methods improve structural reliability assessment [7,8,9,10].

Hybrid renewable systems support energy transition and offshore system integration [13–14].
Future research should focus on climate-adaptive design and advanced monitoring systems [9,15].

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