

INTRODUCTION

Renewable energy is vulnerable to **climate change** and **extreme weather events**. We present ***Energy-Indicators***, a tool developed under the **Destination Earth initiative** to deliver tailored, **streaming-mode** (on-the-fly, seamlessly) climate information alongside **high-resolution** (km-scale) model outputs **synchronously**.

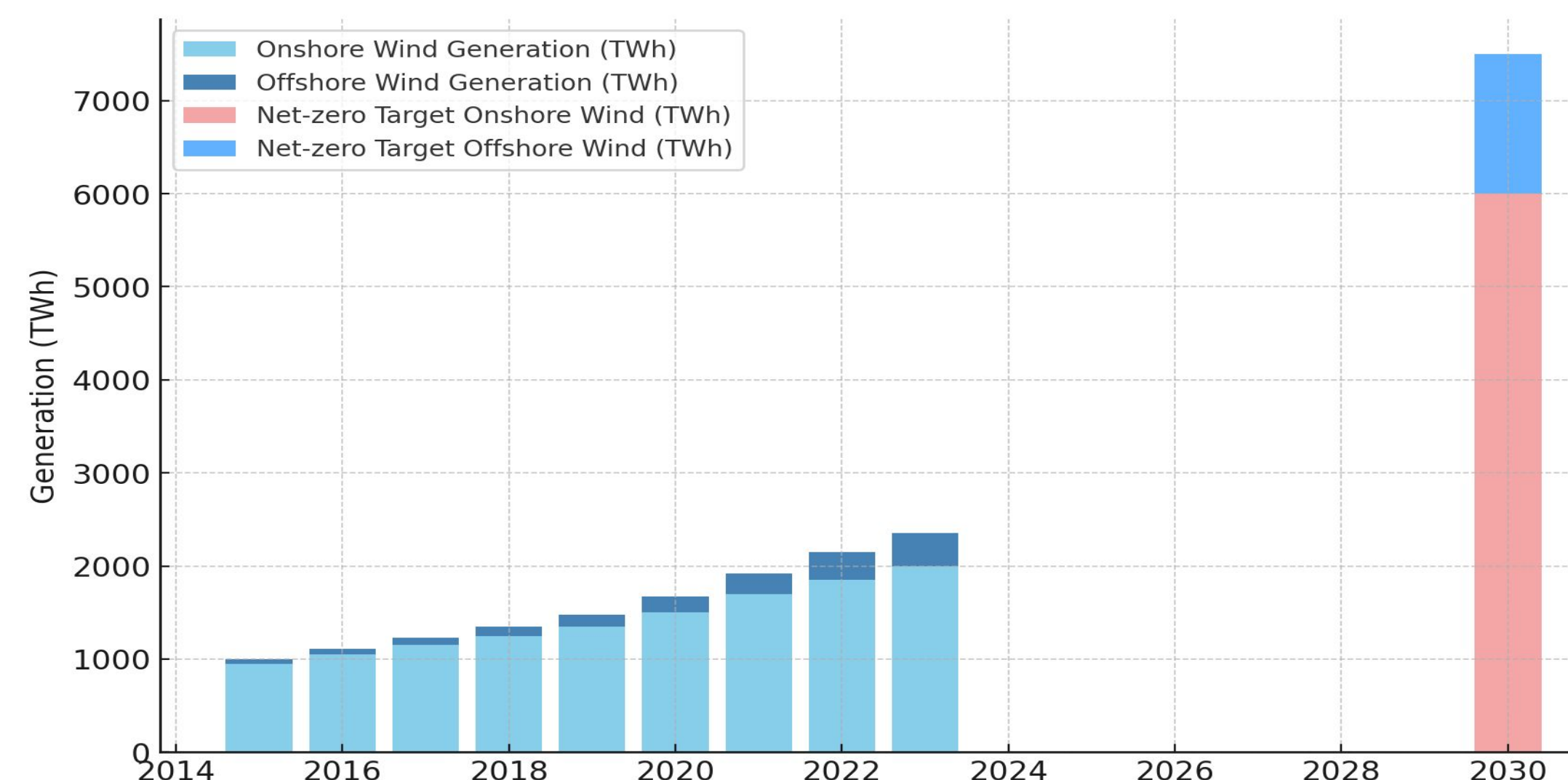


Figure 1 Global wind power generation (onshore and offshore) for the period 2015-2023 and target for 2030 to achieve net zero emissions by 2050 (NZE Scenario) [1]. Source: International Energy Agency (IEA) 2023; "Wind power generation in the Net Zero Scenario, 2015-2030", License: CC BY 4.0

TECHNICAL DESIGN

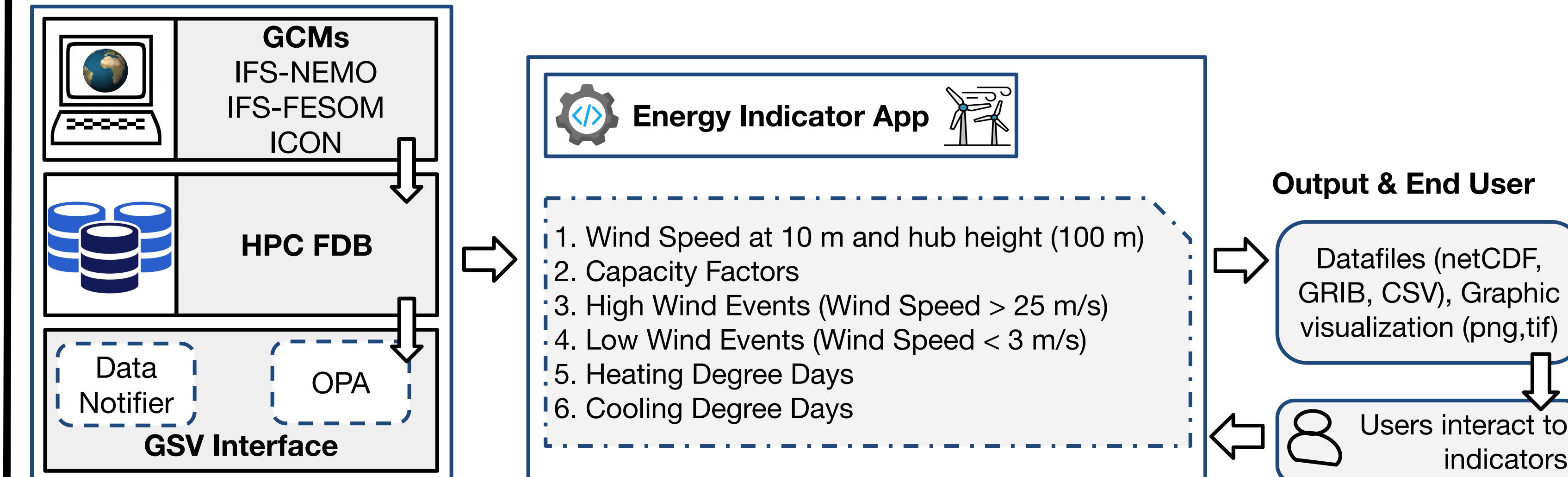
Table 1: Summary of novel features introduced by the ClimateDT in GCMs*

Feature	State-of-the-art	ClimateDT Simulations
Climate variable	10m wind components (u10, v10) Requires interpolation	100m, 10m wind speed & its components.
Temporal resolution	3 to 6 hourly	hourly
Spatial resolution	100 km (CMIP) 12.5 - 50 km (CORDEX)	5 - 10 km*
Location	RCMs / downscaling required for regional climate information	Regional climate information available globally

**Climate Digital Twin (DT) GCMs: IFS-NEMO, IFS-FESOM and ICON*

Visualizations in the following sections: IFS-NEMO historical simulation (1990-2020) at 9 km resolution.

WORKFLOW & ENERGY-APPLICATION



Data listening mechanism: Software that automatically notifies the downstream workflow that data is available (2).

One-pass algorithms (OPA): Mathematical algorithms that compute statistics required by the user on the stream data [3].

Generic State Vector (GSV): A standardised representation of the climate model output, that can be seamlessly used by data consumers downstream.

LOCAL/REGIONAL TAILORED INFORMATION GLOBALLY

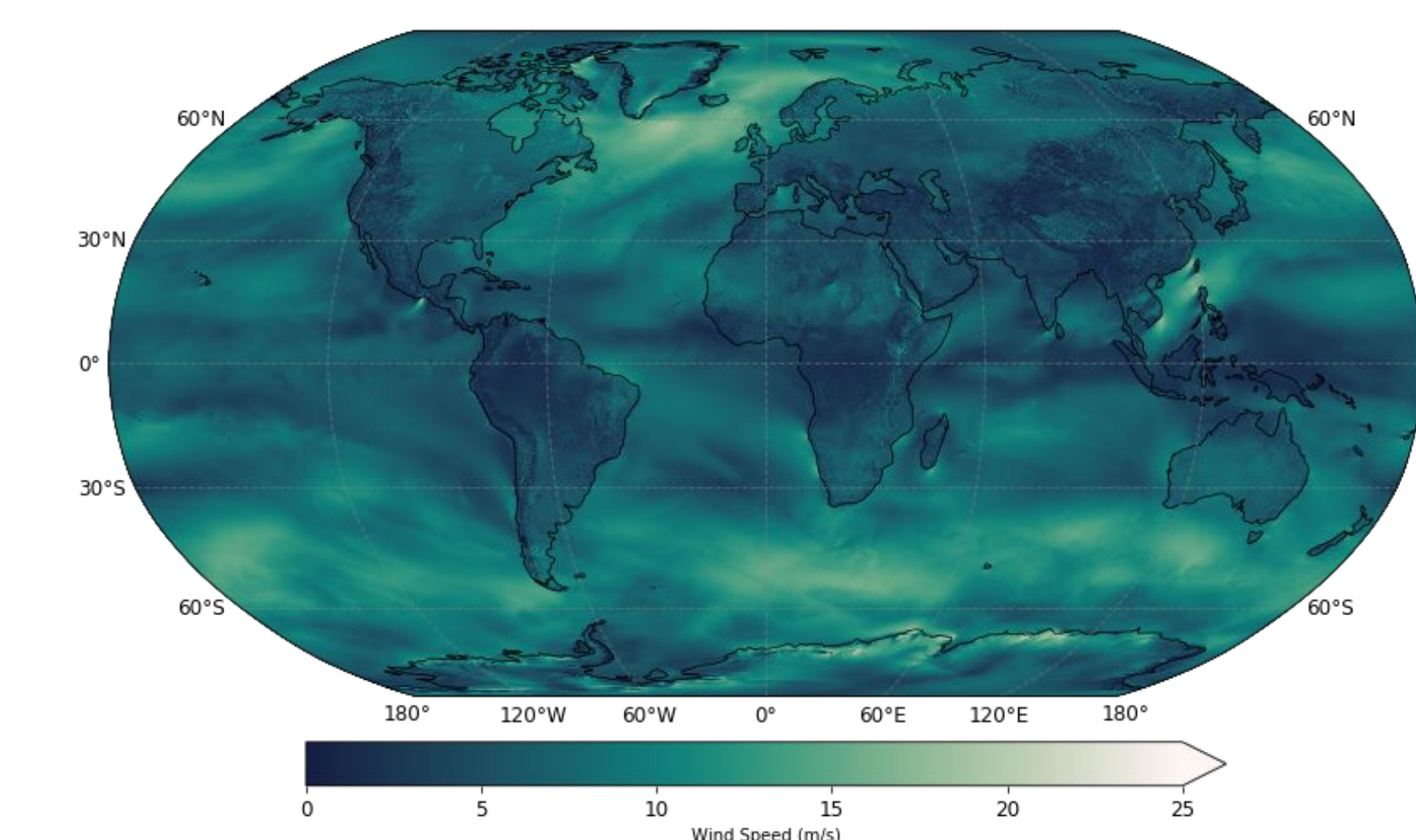


Figure 2 Wind speed at 100m averaged over one week from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation.

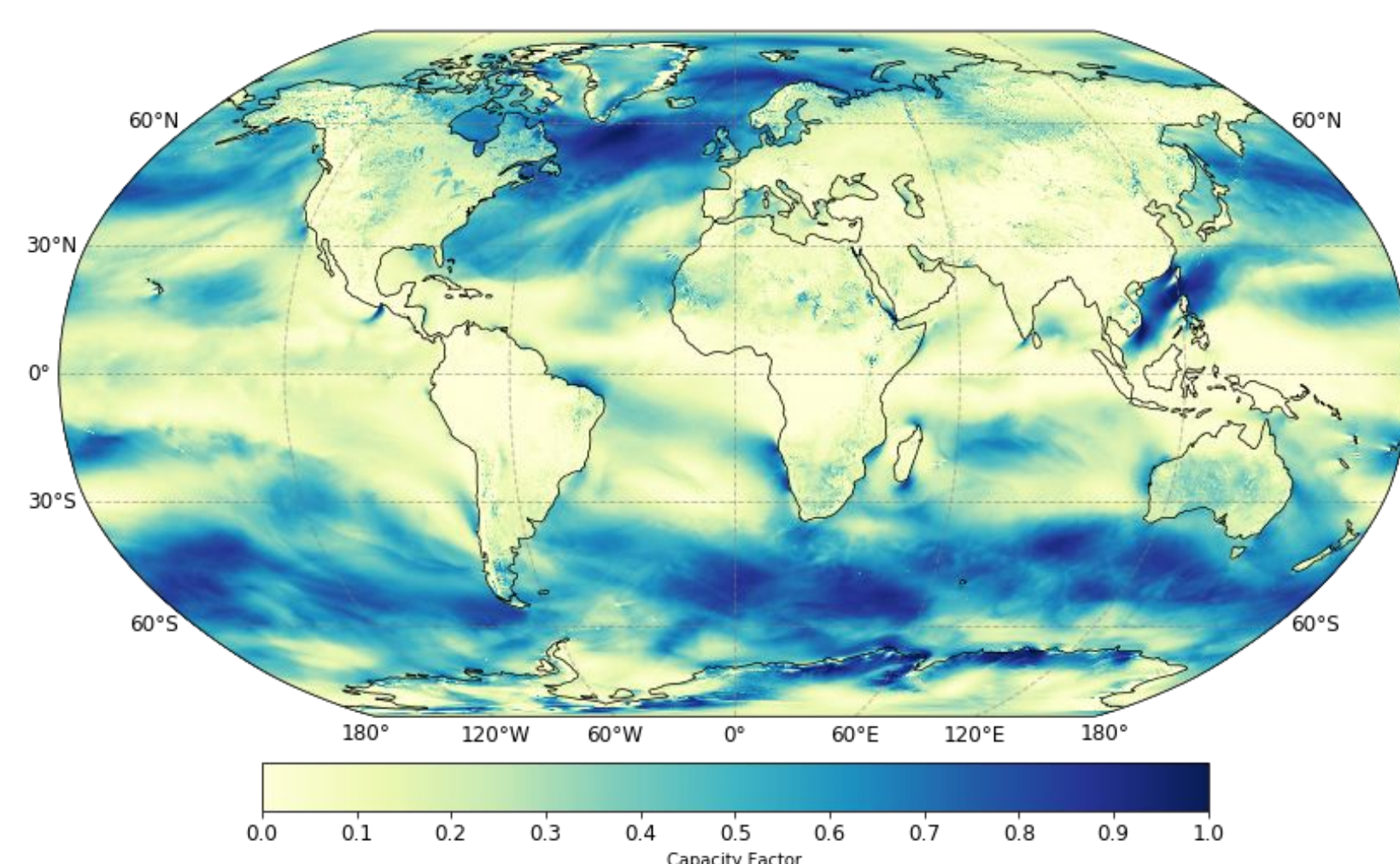


Figure 3 Capacity factor at 100m hub height for a class S Vestas V164 wind turbine, averaged over one week and computed from 1-hourly wind components (100u, 100v). Data was obtained from the ClimatedT IFS-NEMO historical simulation.

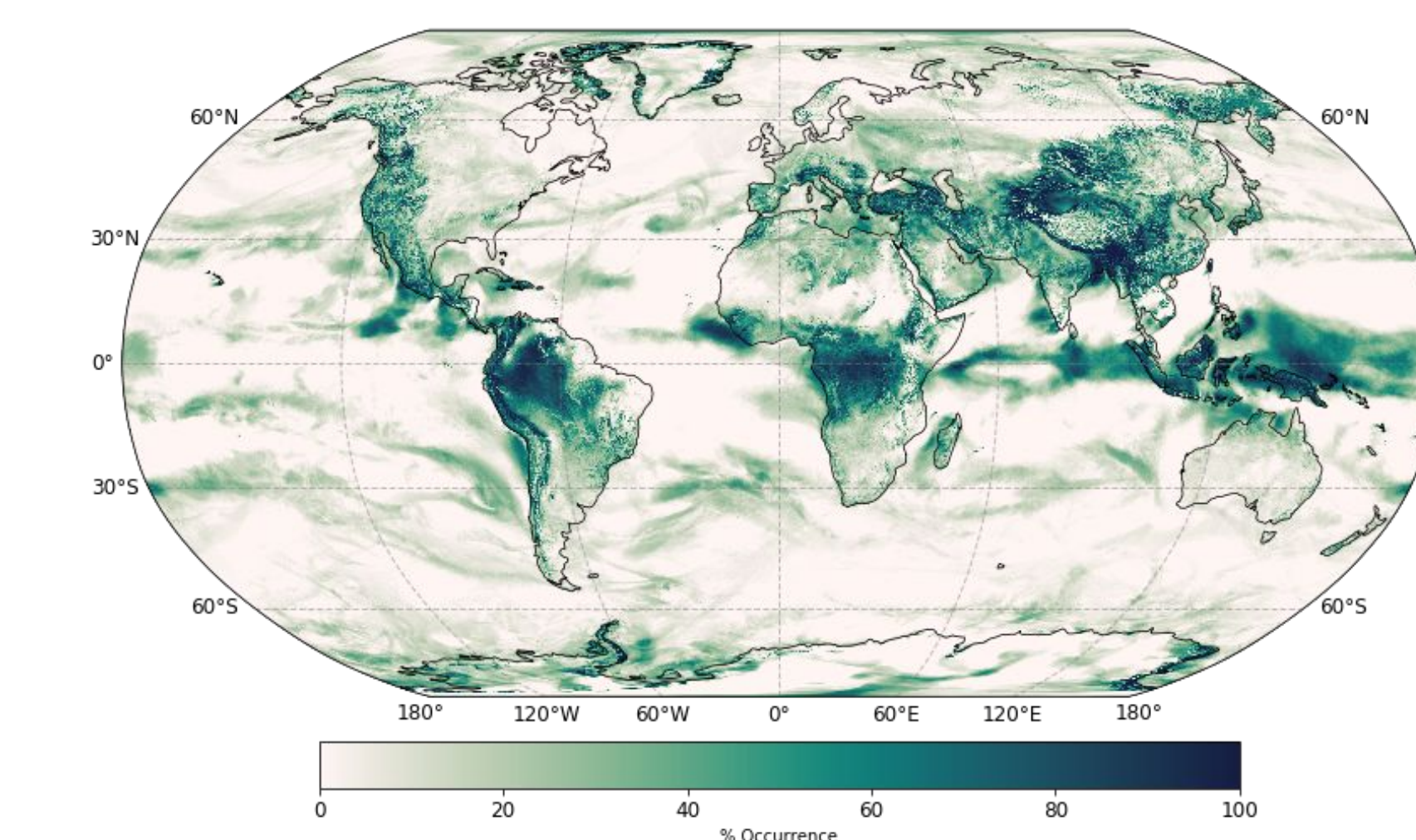


Figure 4 Percentage occurrence of Low Wind Events (LWE) at 100m accumulated over one week from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation. The threshold for LWE: Wind Speed below 3m/s.

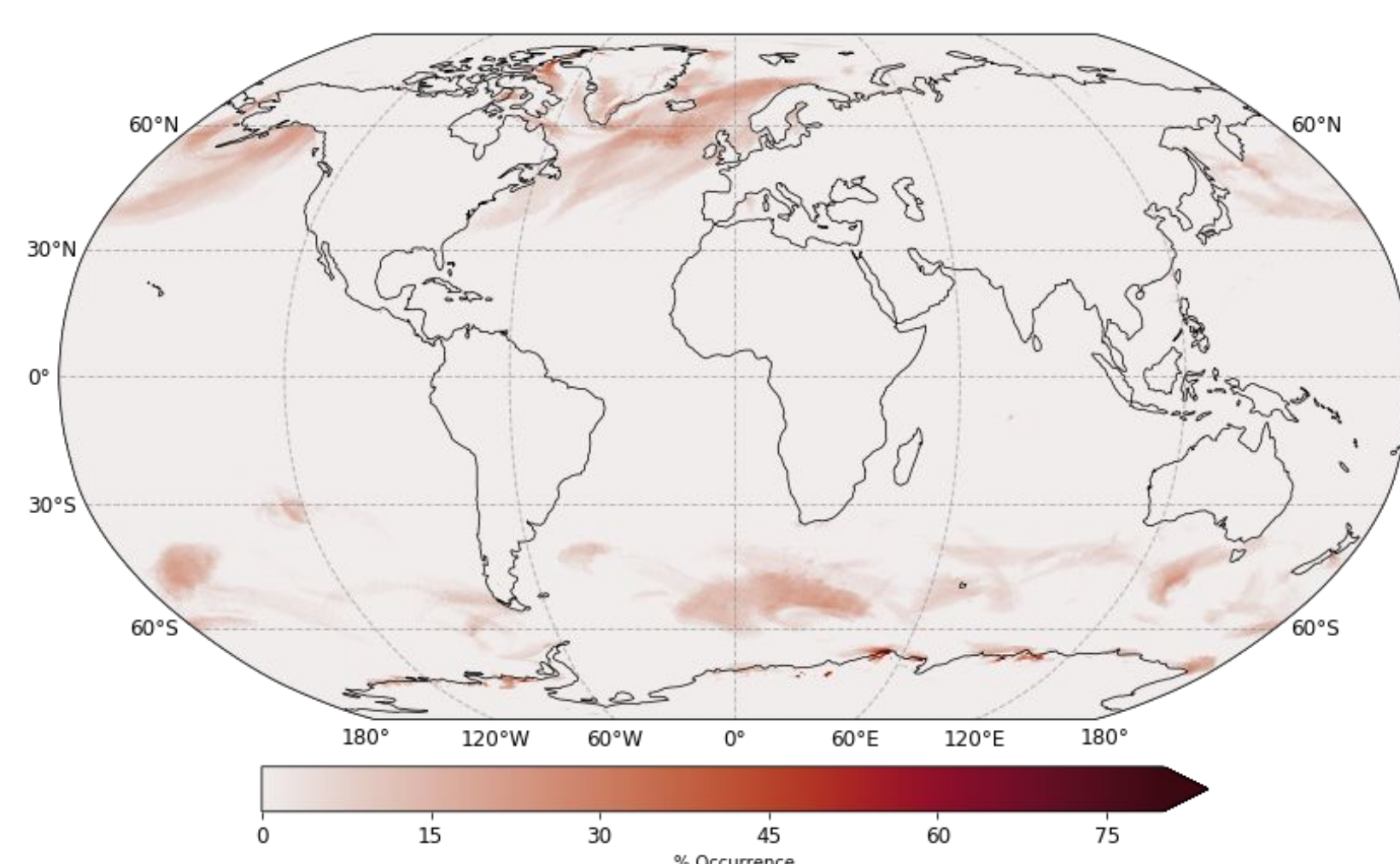
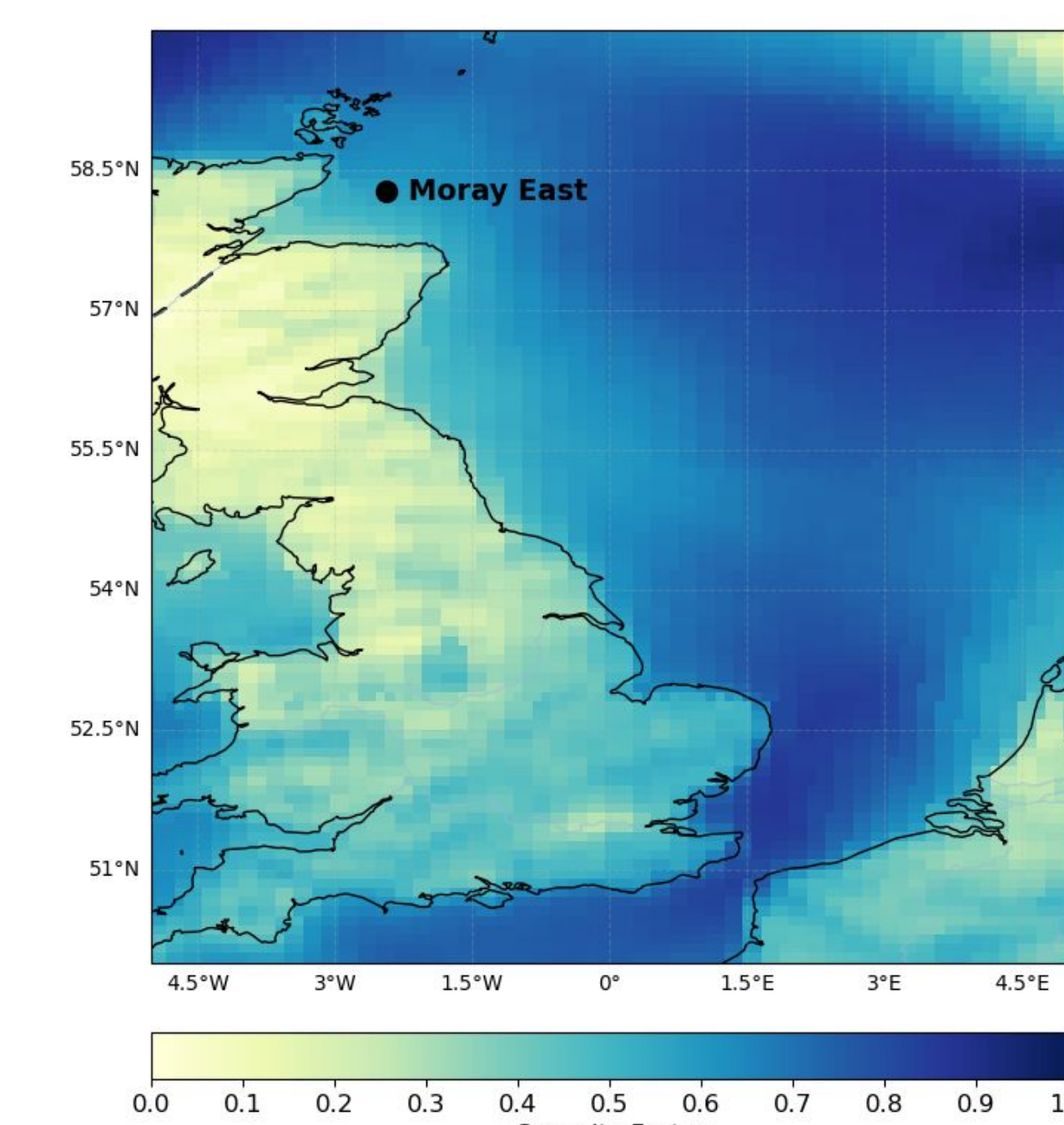
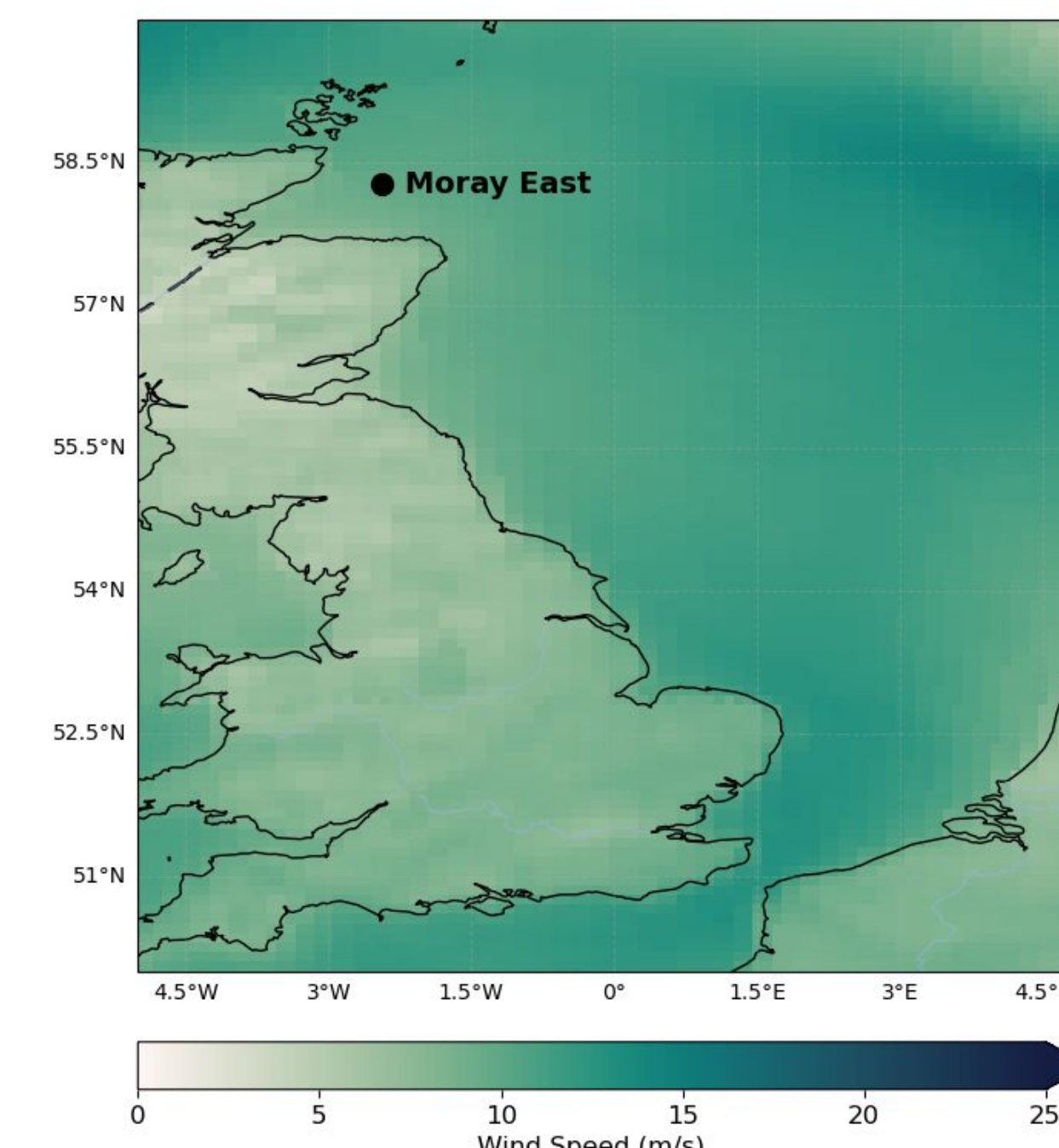


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KEY-USER SPECIFIC TAILORED INFORMATION



The **North Sea** is one of the most promising regions for wind energy and is home to the world's largest offshore wind farm, with a capacity of ~1300 MW [4]. More than 11 countries have wind farms in the area, and one of our **key users**, Ocean Winds, also operates wind farms there.

Figure 6 Wind speed at 100m (left) same as **Figure 2** but over North Sea (a potential wind resource zone). The black dot shows the operational wind farm of Ocean Winds (key-user). Capacity factor at 100m hub height (right) same as **Figure 3** but over North Sea.

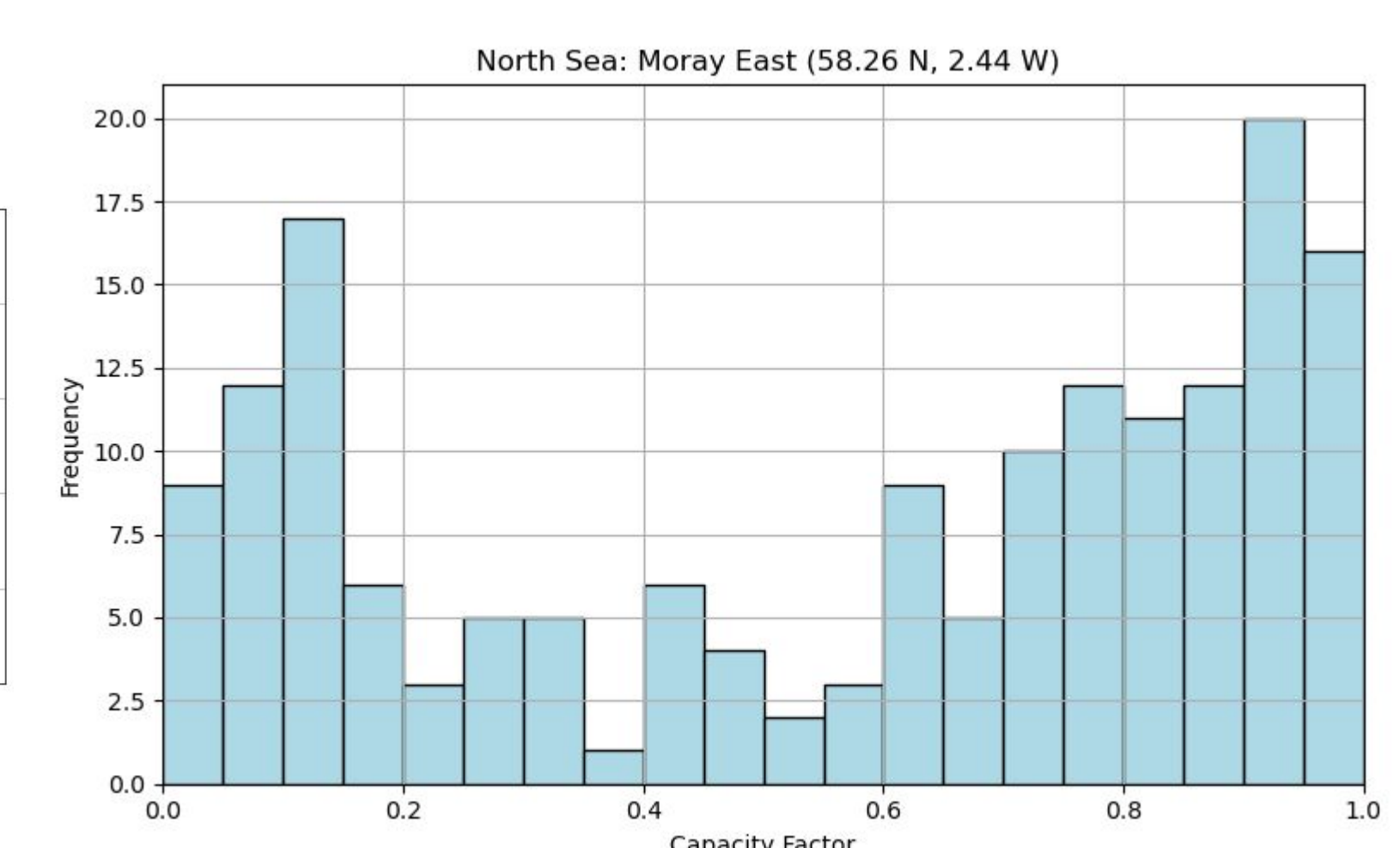
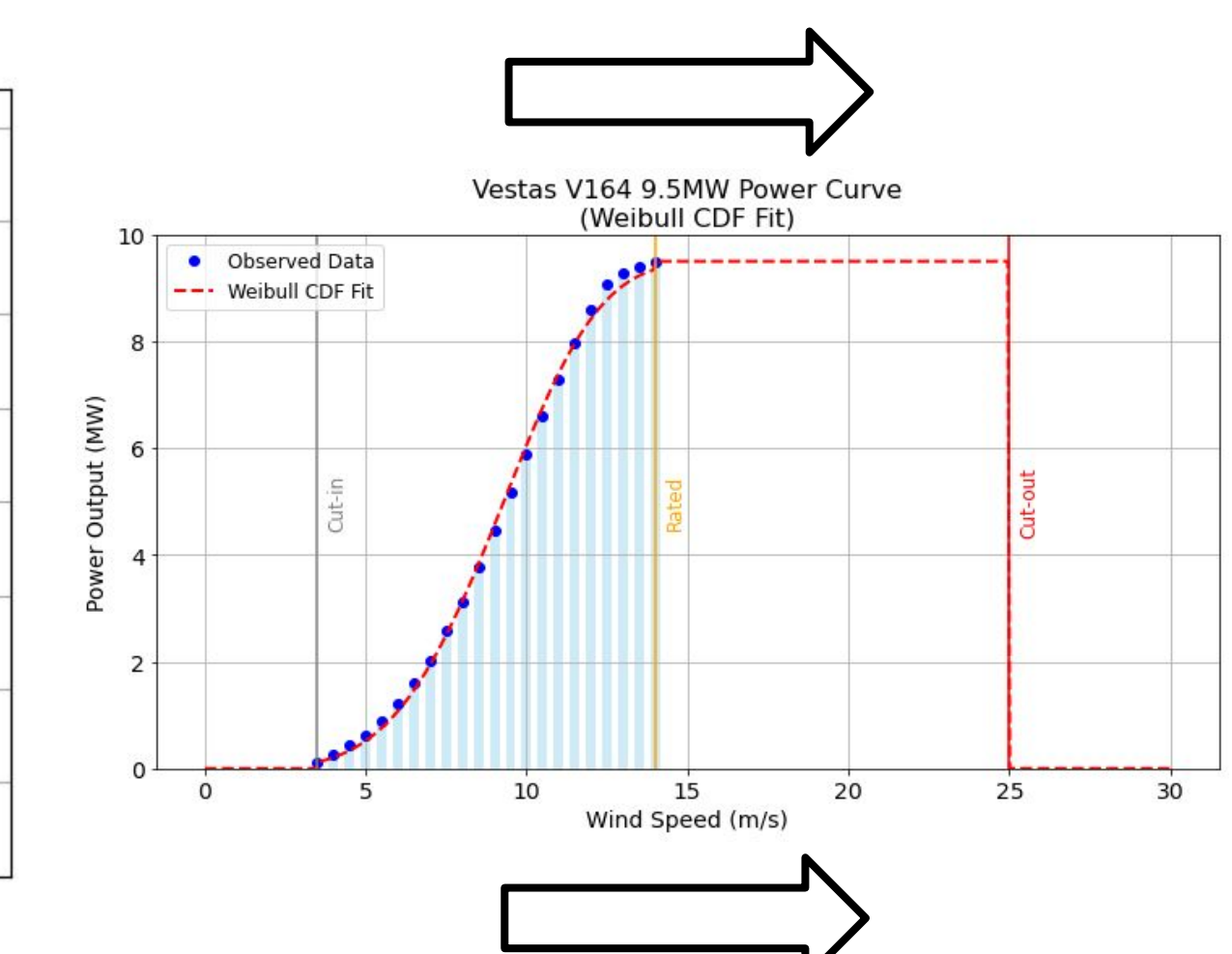
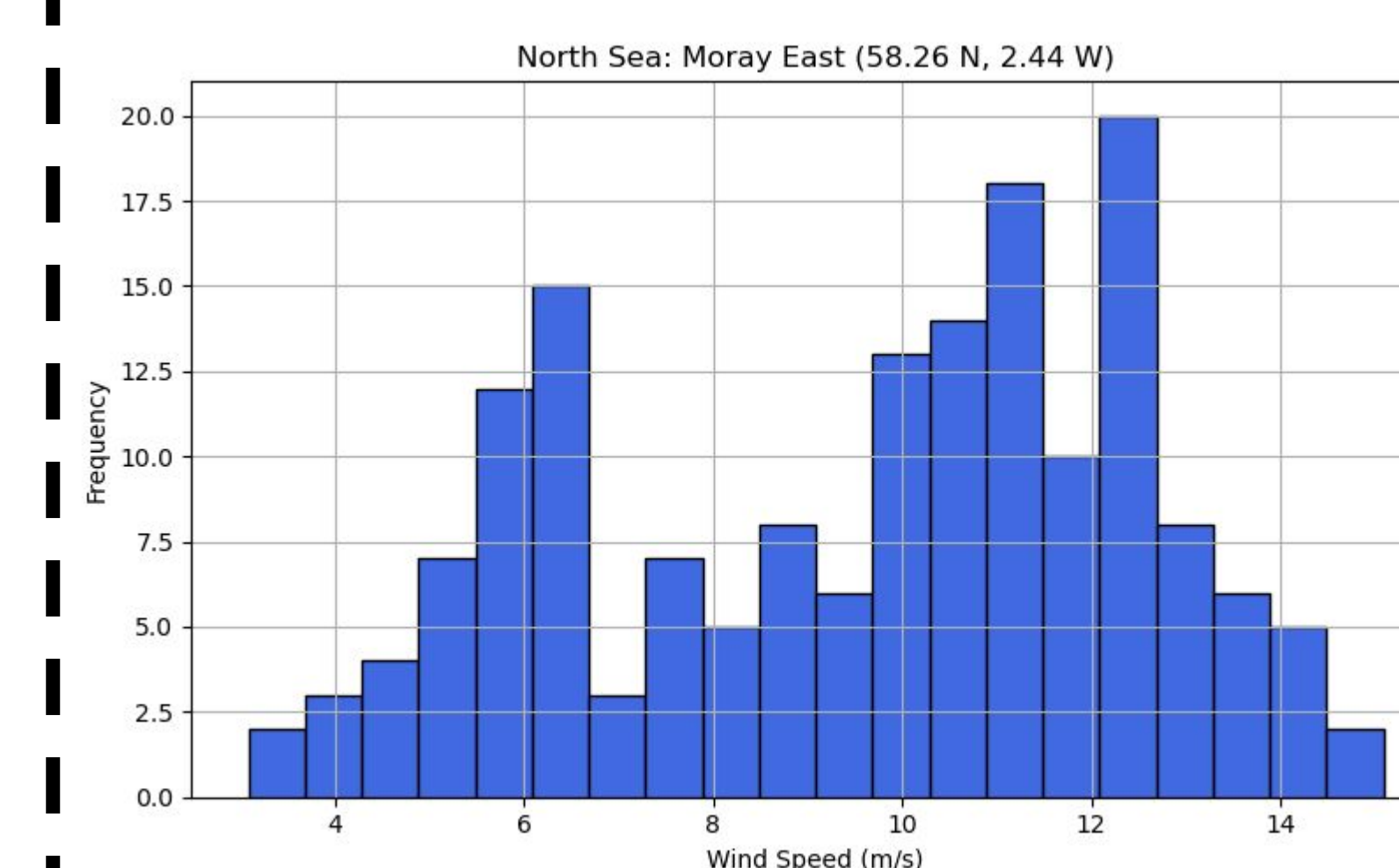


Figure 7 Distribution of Wind Speed (left) and Capacity Factor (right) over Moray East for class S Vestas V164 wind turbine over one week and computed from 1-hourly wind components (100u, 100v). Manufacturer power curve (relation between wind speed and power) for Vetas V164 wind turbine with Weibull CDF approximation (center).

SUMMARY

1. Under the Climate Digital Twin initiative, the Energy-Indicators application plays a crucial role towards the operationalization of km-scale climate data for climate-sensitive impact sectors.
2. The application is capable of transforming km-scale global climate data into regional to local actionable insights tailored to the renewable energy sector.



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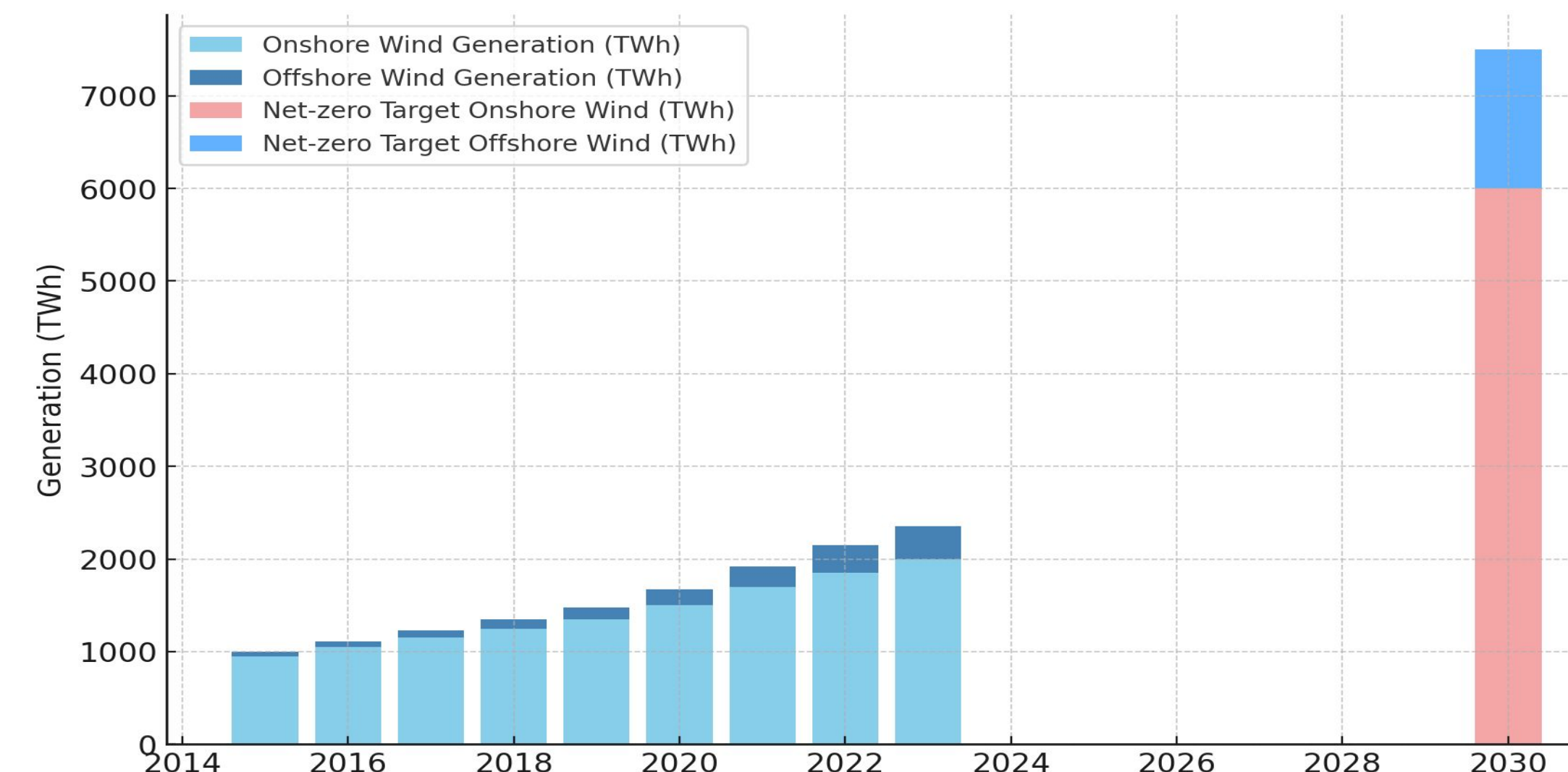


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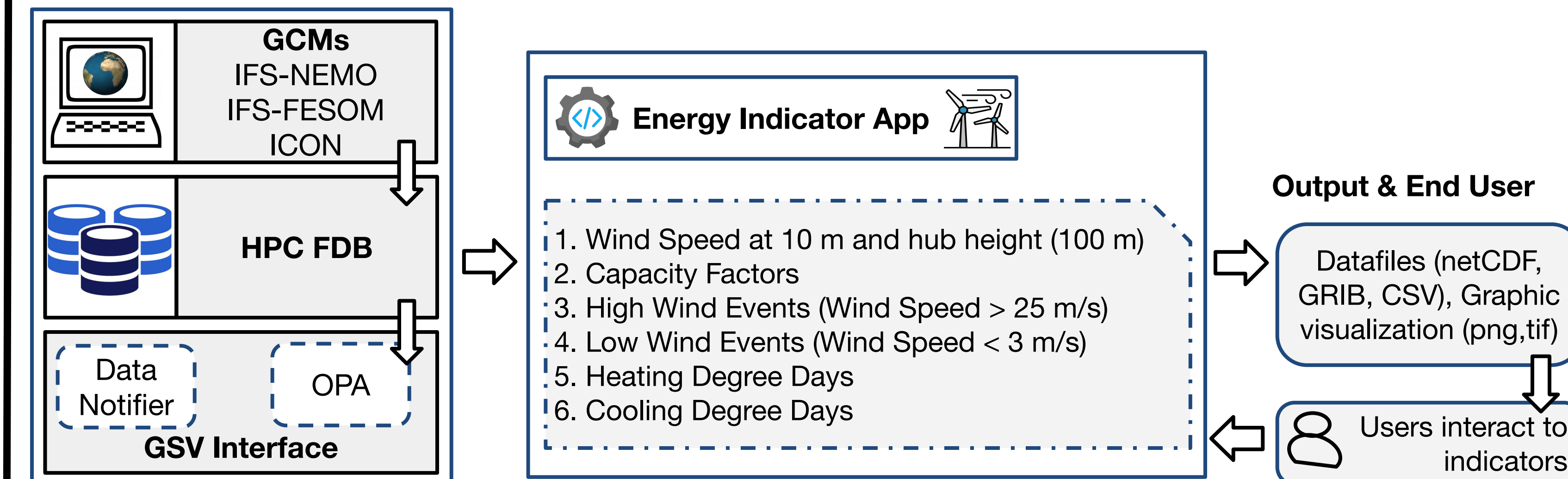
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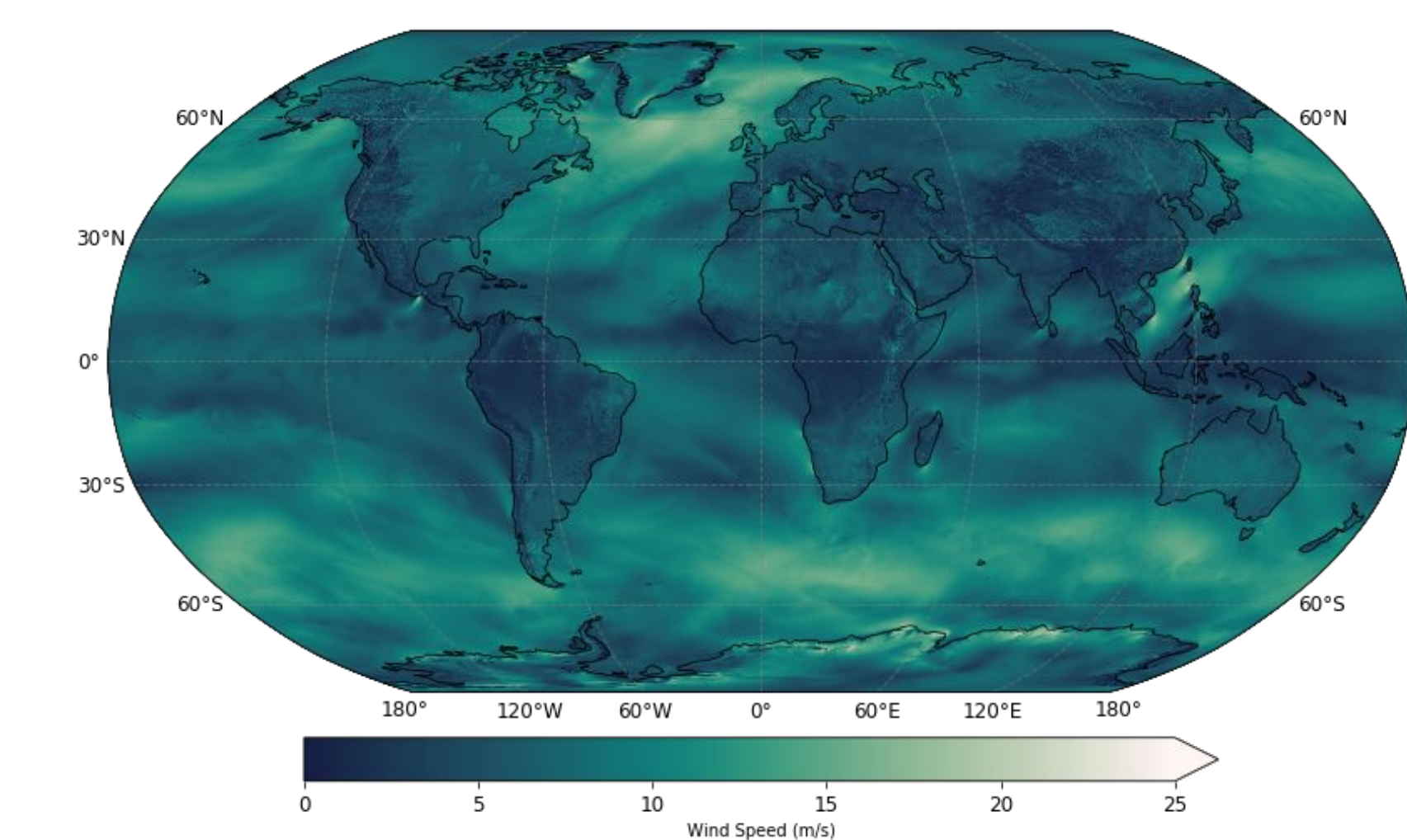


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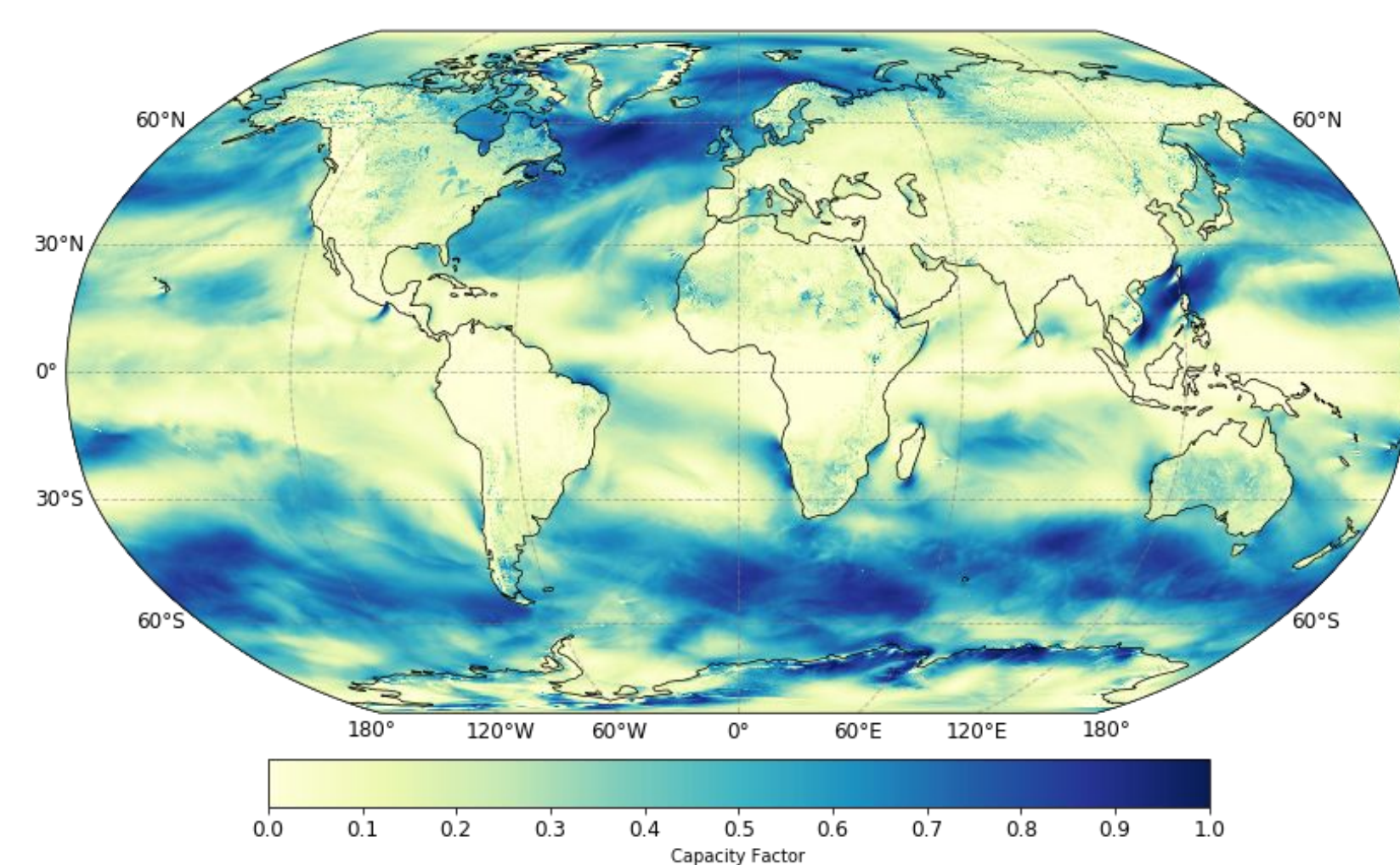


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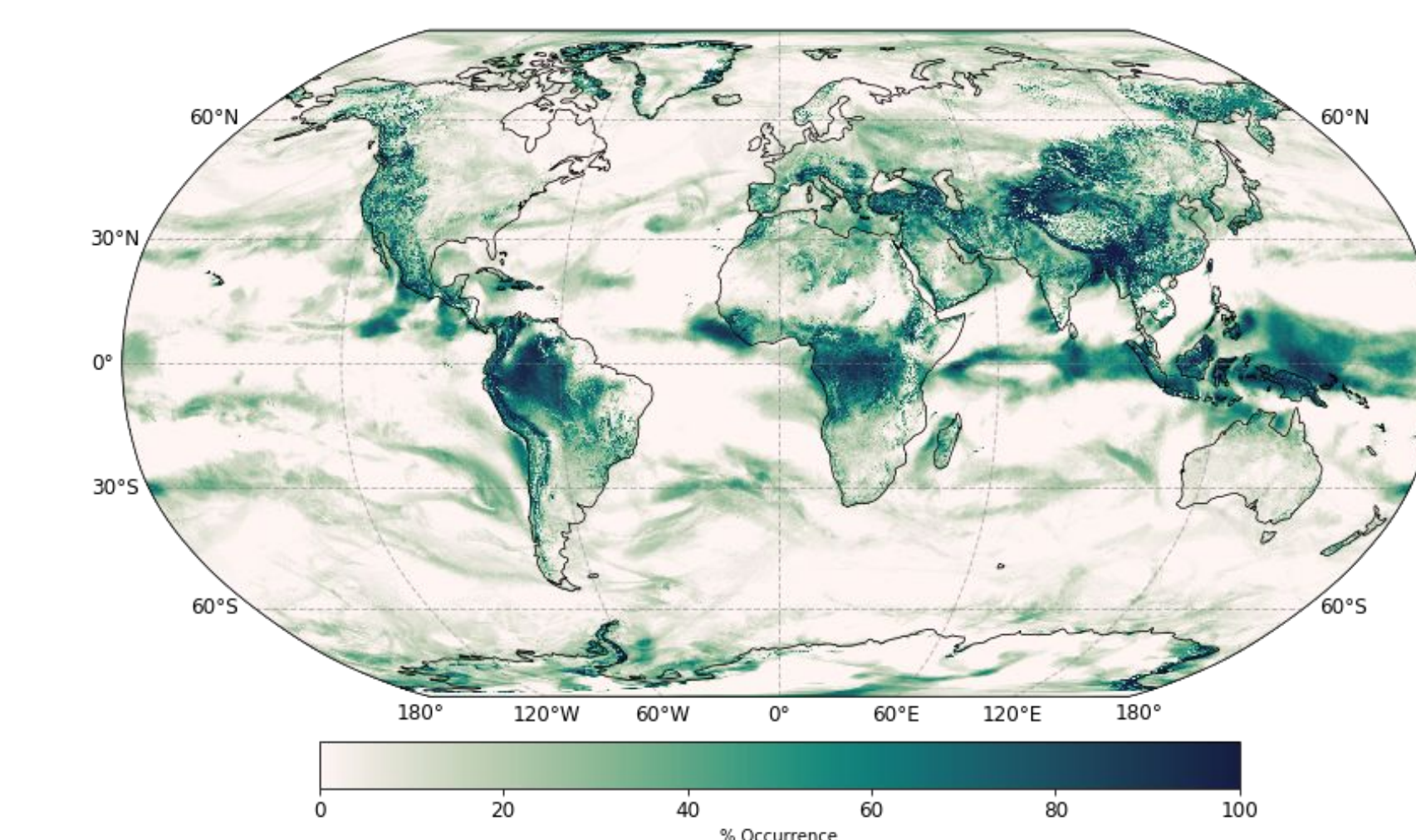


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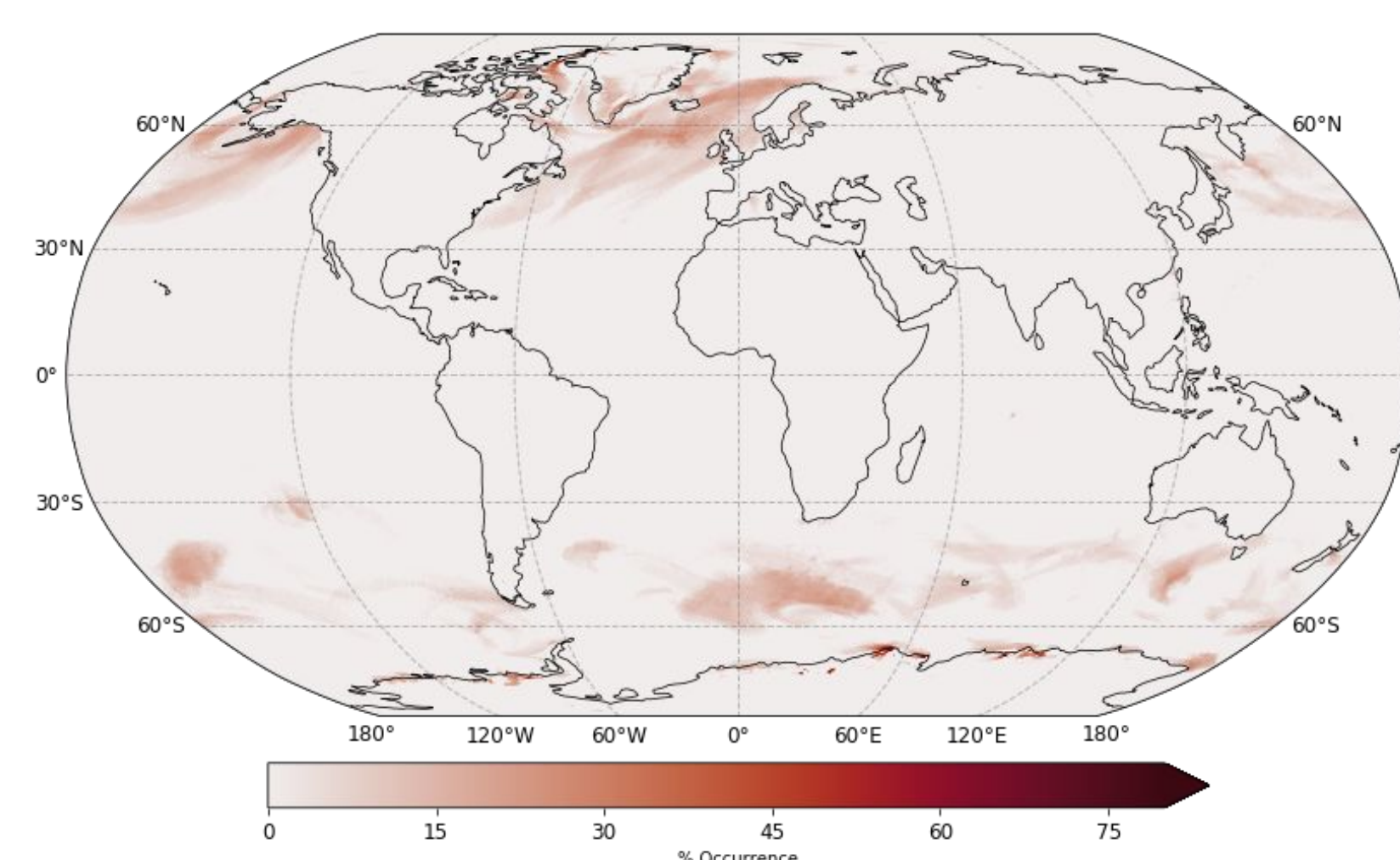


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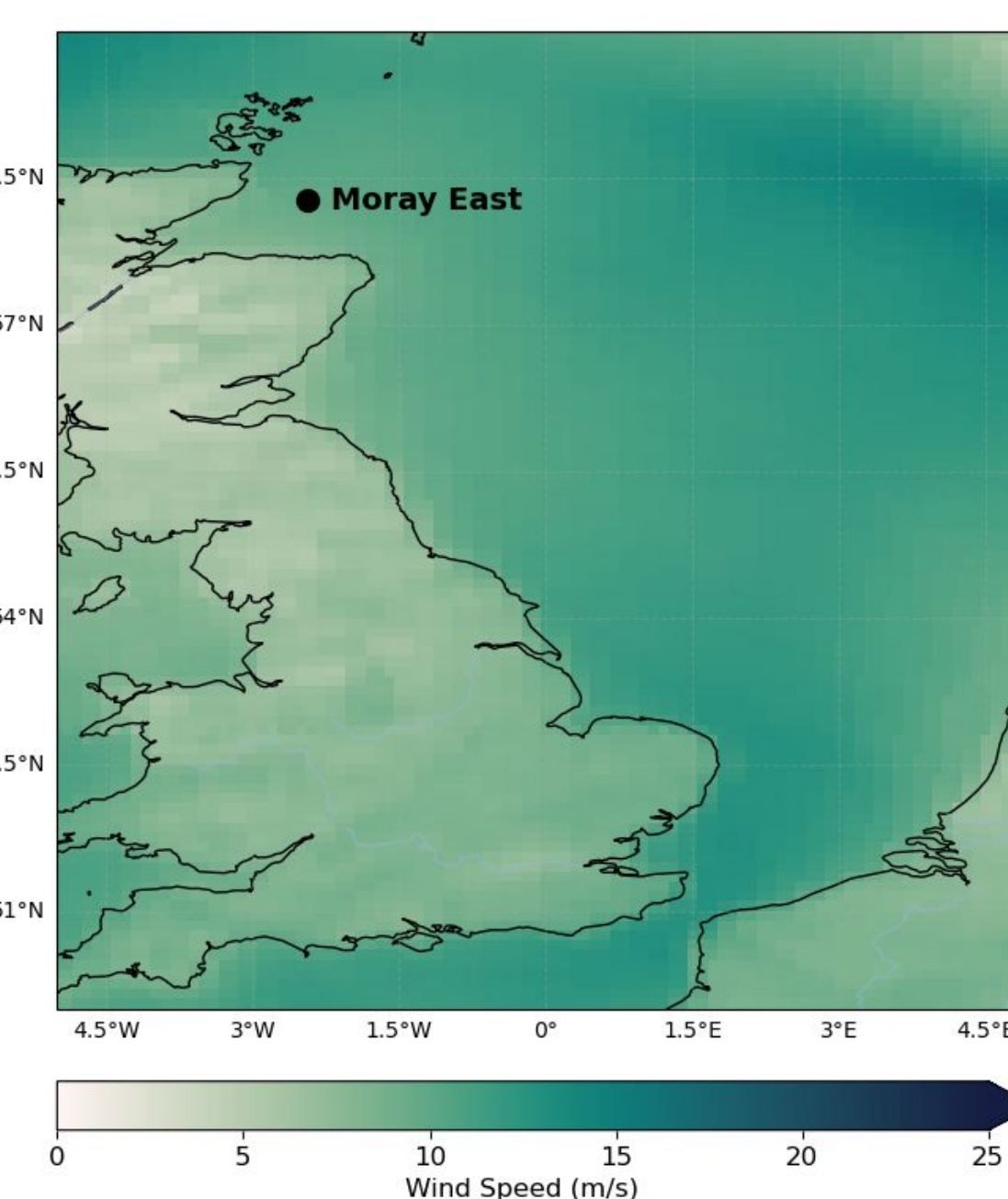


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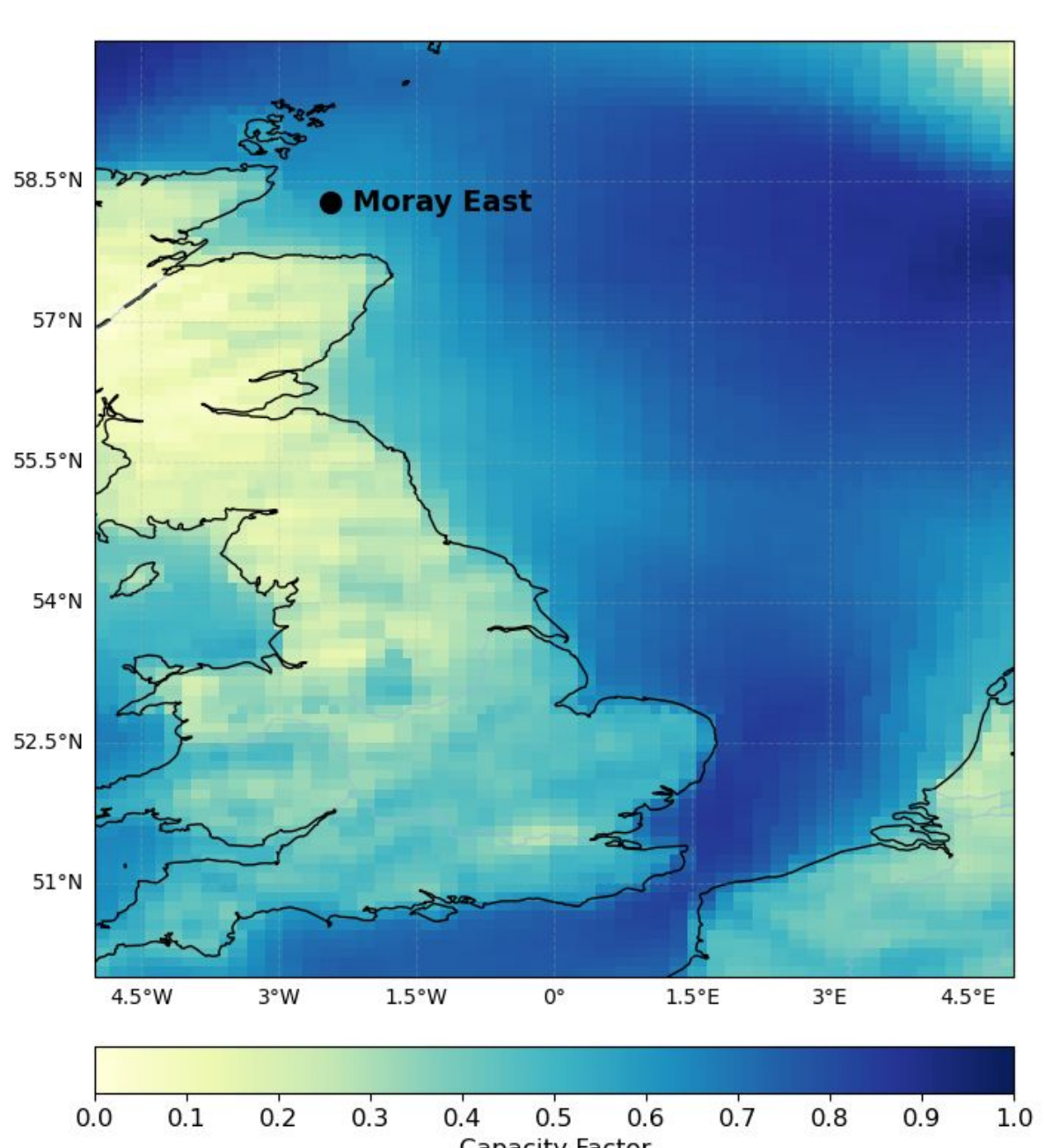


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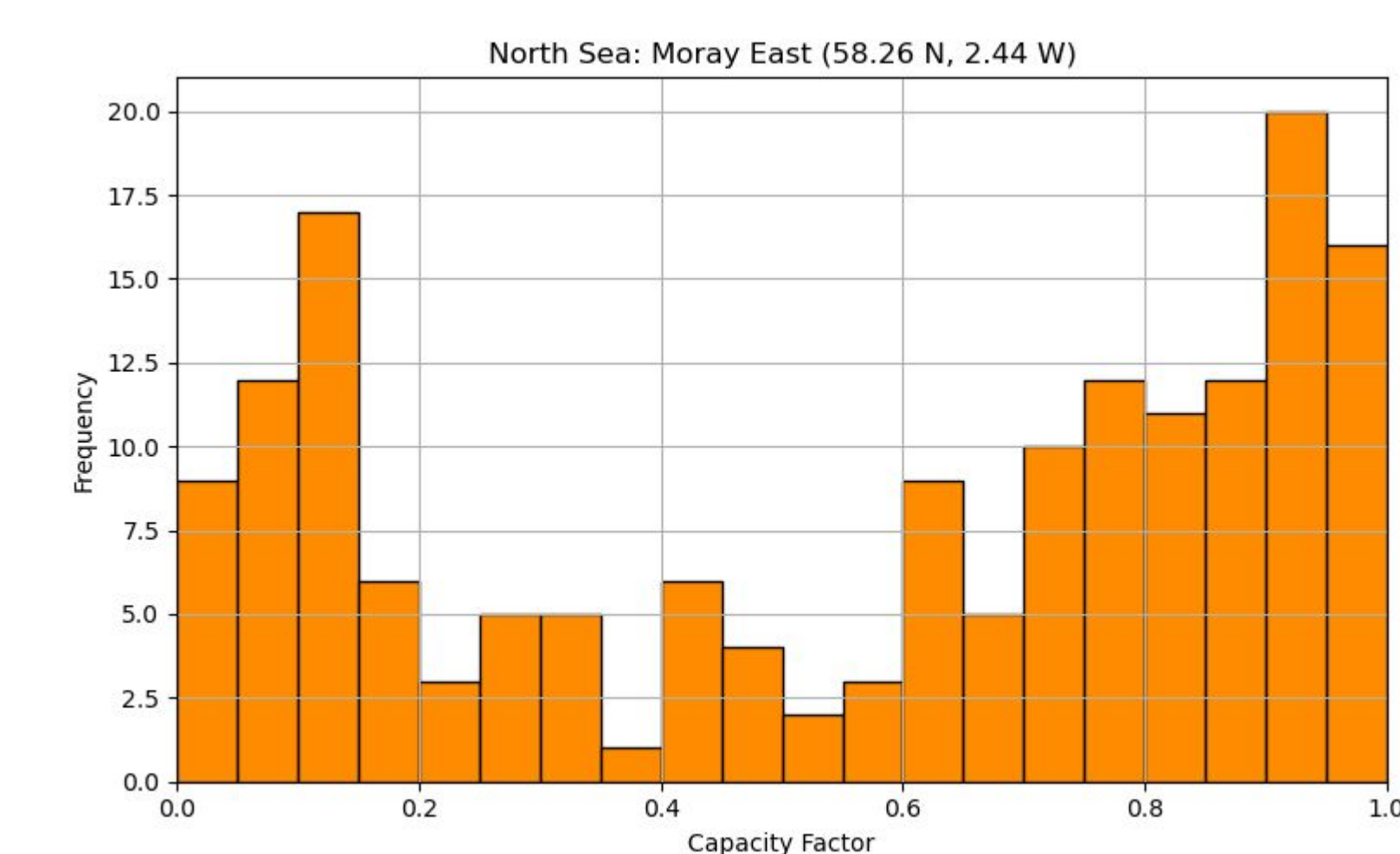
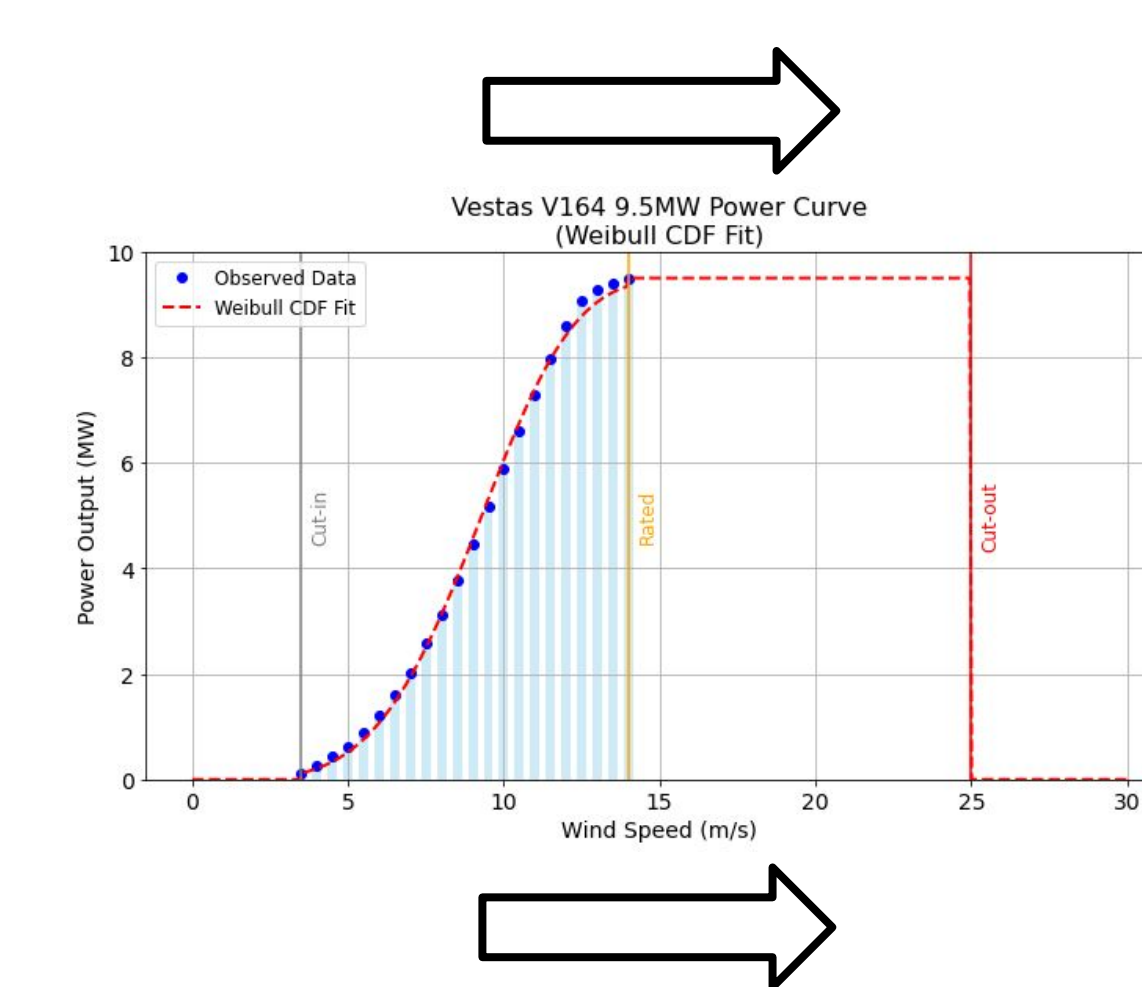
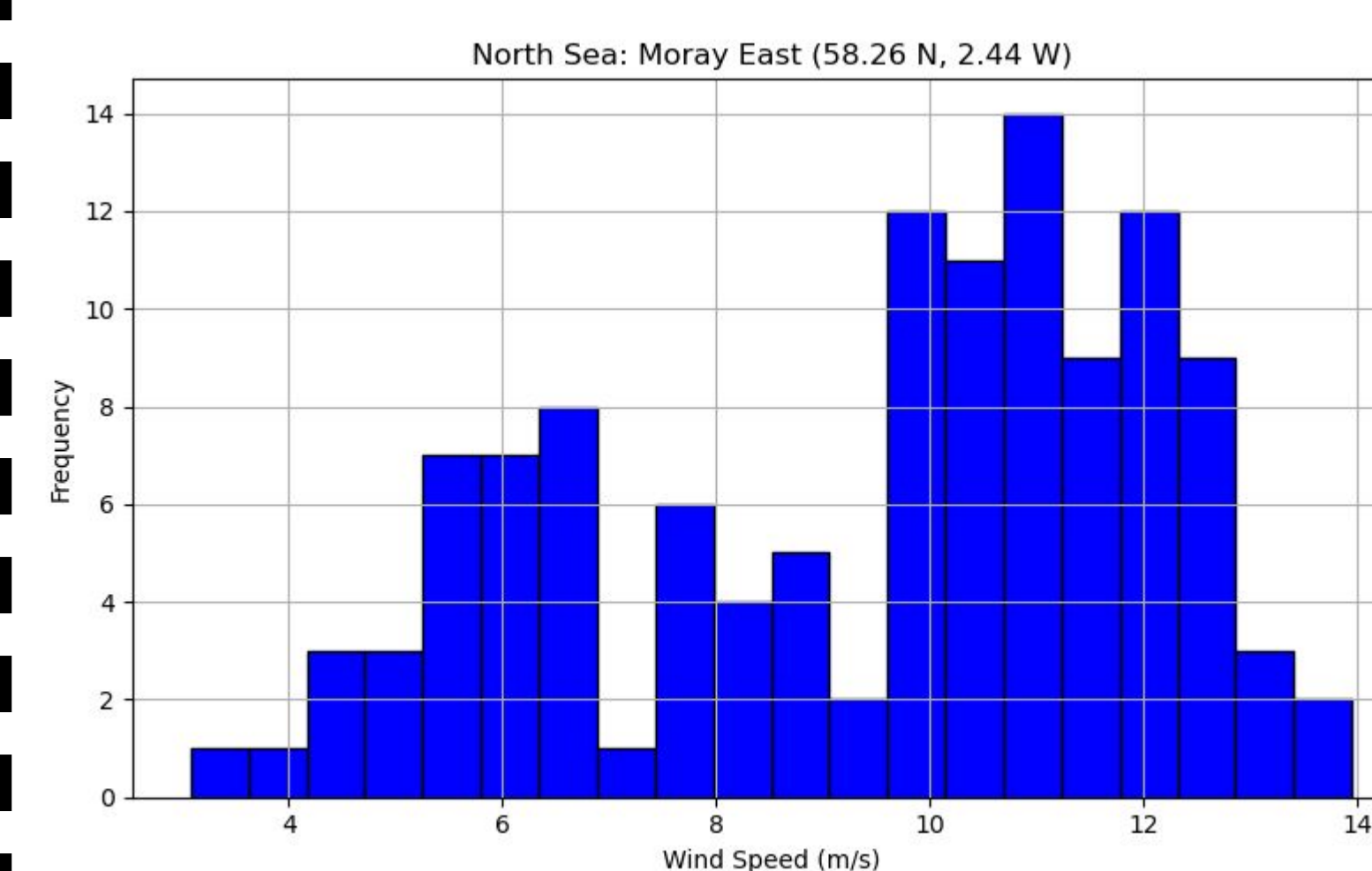


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REFERENCES

1. International Energy Agency (IEA), 2023, <https://www.iea.org/energy-system/renewables/wind>
2. Roura-Adserias, F., i Avila, A. G., i Mikele, L. A., Andrés-Martínez, M., Mora, D. B., Yeregui, I. G., ... & Castrillo, M. (2024). The data streaming in the Climate Adaptation Digital Twin: a fundamental piece to transform climate data into climate information (No. EGU24-2164). Copernicus Meetings.
3. Grayson, K., Thober, S., Lacima-Nadolnik, A., Sharifi, E., Lledó, L., and Doblas-Reyes, F.: Statistical summaries for streamed data from climate simulations: One-pass algorithms (v0.6.2), EGUSphere [preprint], <https://doi.org/10.5194/egusphere-2025-28>, 2025.

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