DESTINATION EARTH

Climate Information in Action : Advancing Renewable Energy Services Through Streaming Climate Simulations

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Climate Adaptation Digital Twin (DE340)

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**.

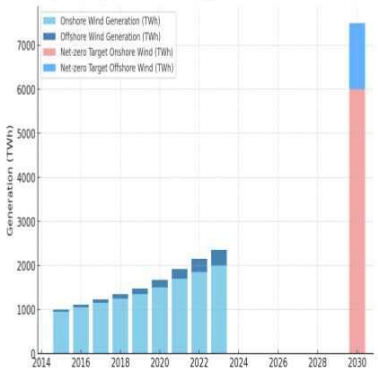


Figure 1 *Global wind power generation (onshore and offshore) for the period 2015-2023 and target for 2030 to achieve net zero emissions by 2050 (NZE Scenario) [1]. Source: International Energy Agency (IEA) 2023; "Wind power generation in the Net Zero Scenario, 2015-2030", License: CC BY 4.0*

TECHNICAL DESIGN

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

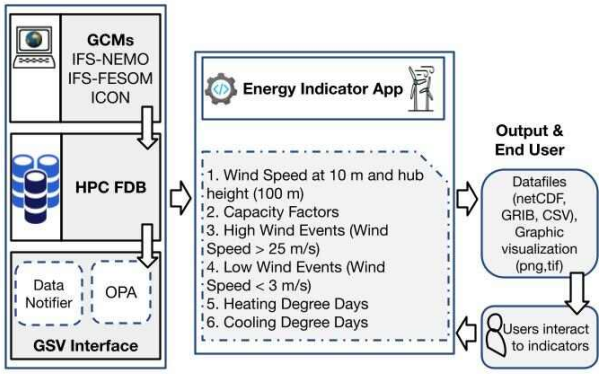
Feature	*State-of-the-art*	*ClimateDT Simulations*
Climate variable	10m wind components (u10, v10) Requires interpolation	100m, 10m wind speed & its components.
Temporal resolution	3 to 6 hourly	hourly
Spatial resolution	100 km (CMIP) 12.5 - 50 km (CORDEX)	5 - 10 km*
Location	RCMs / downscaling required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

Coupled Simulations	Descriptions
Control-1990 (30 yr)	**Fixed** forcings at 1990
Historical + Hist_ensemble	**Transient** forcings 1990-2019, 1990-2014 (3 member ensembles)
Future + Fut_ensemble	SSP3-7.0 forcings from 2020-2040, 2015-2040 (3 member ensembles)

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

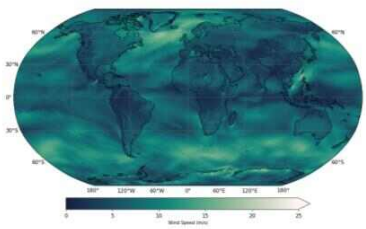


Figure 2 *Wind speed at 100m averaged over one week from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation.*

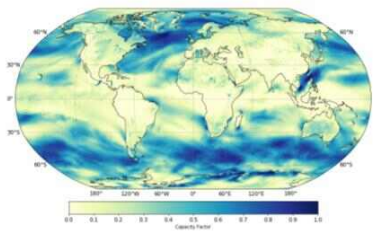


Figure 3 *Capacity factor at 100m hub height for a class S Vestas V164 wind turbine, averaged over one week and computed from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation.*

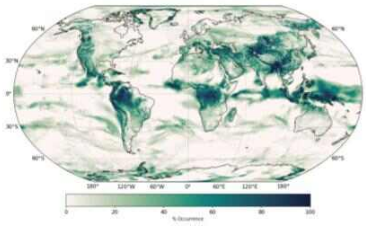


Figure 4 *Percentage occurrence of Low Wind Events (LWE) at 100m accumulated over one week from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation. The threshold for LWE: Wind Speed below 3m/s.*

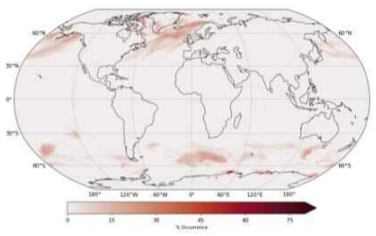


Figure 5 *Percentage occurrence of High Wind Events (HWE) at 100m accumulated over one week from 1-hourly wind components (100u, 100v). Data was obtained from the ClimateDT IFS-NEMO historical simulation. The threshold for HWE: Wind Speed above 25m/s.*

KEY-USER SPECIFIC TAILORED INFORMATION

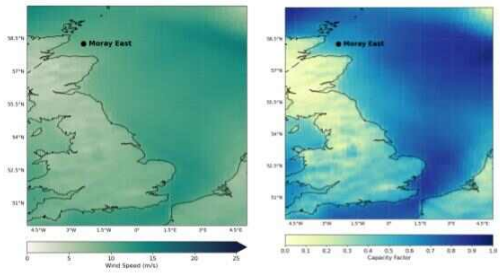


Figure 6 *Wind speed at 100m (left) same as **Figure 2** but over North Sea (a potential wind resource zone). The black dot shows the operational wind farm of Ocean Winds (key-user). Capacity factor at 100m hub height (right) same as **Figure 3** but over North Sea.*

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.

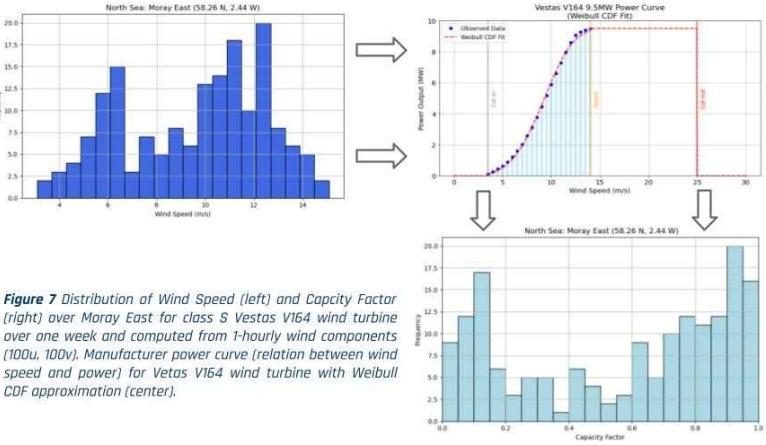


Figure 7 *Distribution of Wind Speed (left) and Capcity Factor (right) over Moray East for class S Vestas V164 wind turbine over one week and computed from 1-hourly wind components (100u, 100v). Manufacturer power curve (relation between wind speed and power) for Vetas V164 wind turbine with Weibull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

SUMMARY

- 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.
- The application is capable of transforming km-scale global climate data into regional to local actionable insights tailored to the renewable energy sector.

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.
4. Chirosca, Ana-Maria, Liliana Rusu, and Anca Bleoju. "Study on wind farms in the North Sea area." Energy Reports 8 (2022): 162-168.

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