Seamless climate information for enhancing energy system resilience in Spain

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RENEWABLE ENERGY: A CLIMATE SENSITIVE SECTOR

The climate-dependent nature of renewable energy introduces significant challenges related to variability, reliability, and integration into the power system. In this context, climate predictions across multiple timescales can support energy system planning and operation decisions (Fig 1). These predictions allow the anticipation of both energy demand and supply-side variability, which reduces climate risks and enhances decision-making capabilities.

Climate predictions

Sub-seasonal	Seasonal	Decadal	Climate projections
10 d-1 month	1 month–6 months	1-10 years	20-100 years

Time

Applications for wind/solar/hydro generation

Post-construction decisions

Energy producers: resource management strategies
Energy traders: resource effects on markets
Plant operators: O&M, especially offshore wind
Plant investors: anticipate cash flow, optimize investments

Pre-construction decisions

Power plant developers: Site selection. Future risks assessment.
Investors: Evaluate return on investments
Policy-makers: Asses changes to energy mix
River-basin managers: manage the river flow

Applications for electricity demand

Mid-term planning

Grid operators: Anticipate hotter/colder seasons. Schedule power.
Energy traders: Anticipate energy prices.

Long-term planning

Grid operators: Anticipate addition of more capacity. Adaptation of transmission lines
Policy-makers: Plan addition of more capacity. Understand changes to energy mix

Figure 1. *Decisions in the renewable energy sector that can benefit from the use of climate information at multiple timescales (sub-seasonal, seasonal and decadal).*

BOREAS PROJECT

BOREAS project is developing seamless climate products across all timescales to provide consistent, actionable information for decision-making in the renewable energy sector. By working closely with stakeholders, the project ensures that climate tools are user-driven, supporting both day-to-day operations and long-term strategies for energy transition and climate adaptation.

ADVANCING CO-PRODUCTION OF SEAMLESS CLIMATE INFORMATION FOR THE ENERGY SECTOR

Different activities have been carried out in BOREAS to interact with the users. These include the co-development of case studies and the joint discussion of the climate information in regular meetings (webinars).

Case studies evaluate the forecasts that users could have received weeks or months in advance for unusual past events that affected the energy system. These case studies have been selected in collaboration with stakeholders for different regions (Fig.2). The outputs of the case studies will be uploaded in the decision support tool.

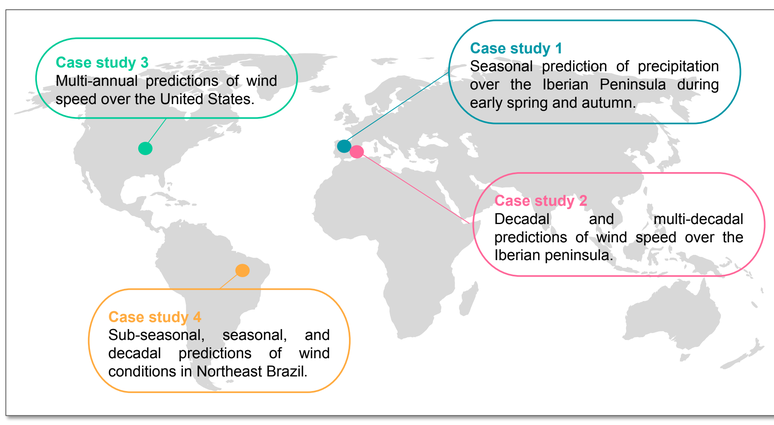

Figure 2. *Case studies co-defined with the users in the renewable energy sector. Specific locations, variables and timescales will be explored in the different case studies.*

Webinars will be organised within the framework of the BOREAS project will organise meetings to discuss the performance of past predictions and the expected conditions for the next months and seasons with the energy users. They will start in Autumn 2025

UNDERSTANDING USERS' NEEDS THROUGH COLLABORATION

The project has mapped a diverse range of stakeholders within the energy sector and has initiated participatory processes, including semi-structured interviews aimed at identifying relevant case studies. Additionally, a multi-stakeholder workshop involving representatives from various organisations has been conducted to facilitate knowledge exchange and co-definition of user needs.

Figure 3*. Flyer (left panel) and pictures (right panel) for the joint workshop BOREAS-NEXTGEM on the climate information at different timescales for the energy transition held in Madrid on the 24th of April 2025.*

METHODS TO BLEND AND ASSESS CLIMATE FORECASTS ACROSS TIMESCALES

01 STATISTICAL DOWNSCALING

Different methods are being used (Duzenli et al. under review, and Moreno-Montes et al. submitted) to provide climate predictions with high resolution. This is very much needed for the integration of climate predictions in the day-to-day activities of the energy sector.

02 TEMPORAL MERGING

Novel techniques re being implemented (Solaraju-Murali et al. 2025, and Delgado-Torres et al. under review) to blend the available forecasts across seasonal to multi-annual timescales in a unified framework. These methods have been designed to bridge the current gap between seasonal predictions (up to 6 months ahead) and decadal predictions (from 1 to 10 years).

03 TAILORED INDICATORS

Climate predictions of wind power density, wind and solar capacity factor, annual production or cooling and heating degree days are being designed to satisfy the users' needs by considering specific thresholds (e.g. type of turbine or time aggregation).

DECISION SUPPORT SYSTEM

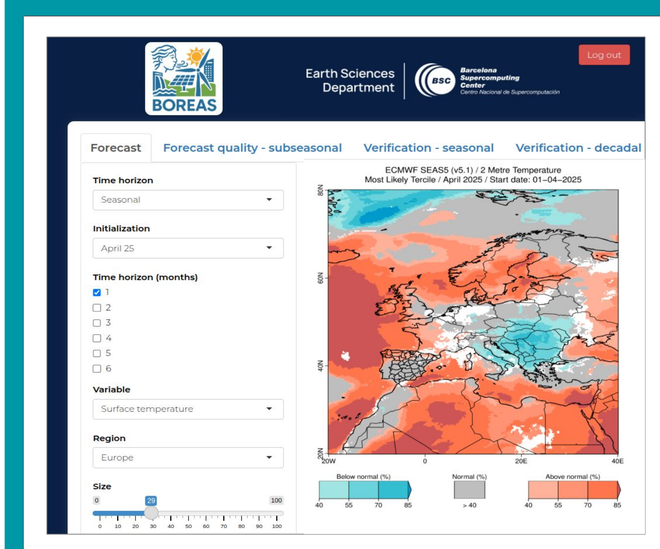

Figure 4. *Decision support tool developed in the BOREAS project.:* https://earth.bsc.es/shiny/ptrascas_BOREAS_fqa/ (User: boreas, Password: climayenergia)

The tool provides **real-time predictions** across timescales (sub-seasonal, seasonal, decadal) under the 'forecast' tab. One example of the seasonal forecasts provided by the tool is shown in Fig. 4. This information can support the renewable energy sector in operational planning.

In addition the app includes a structured **evaluation of forecast quality** for the climate predictions at different time horizons and climate projections.

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