LNEG
Laboratório Nacional de Energia e Geologia, I. P.

Offshore wind resource assessment for Offshore Renewables Planning.

A. Couto and T. Simões

Contributions from: J. Silva, P. Costa, D. Santos, and A. Estanqueiro

EERA JP Wind Workshop - SP3, 14th April 2021

REPÚBLICA PORTUGUESA
AMBIENTE E TRANSIÇÃO ENERGÉTICA

Presentation outline :

A. Wind resource assessment

- Introduction
- Mesoscale modelling features to improve the wind resource characterization
- Development of the new offshore wind Atlas: Model calibration - *Step I*
- New offshore wind Atlas: Atlas Validation - *Step II*

B. Renewables Planning

Introduction

Introduction

- A **reliable offshore wind resource assessment** is a **crucial step to establish a strategic plan for the exploitation of marine renewable energies**. Although:
  - experimental measurement campaigns may not be cost effective, especially for deep offshore regions, and these data are, typically, collected inside a limited spatial and time window,
  - while wind observations inferred through satellites still present large amounts of missing/poor quality data and low spatial/temporal resolution .

- **To achieve this goal**, without resort to an extensive and costly network of anemometric stations or buoys, **it becomes necessary to use the so-called mesoscale numerical models**.

- These models have the **ability to describe important atmospheric phenomena for wind power** purposes such as the atmospheric turbulence, stratification, and sea-land-breeze processes.

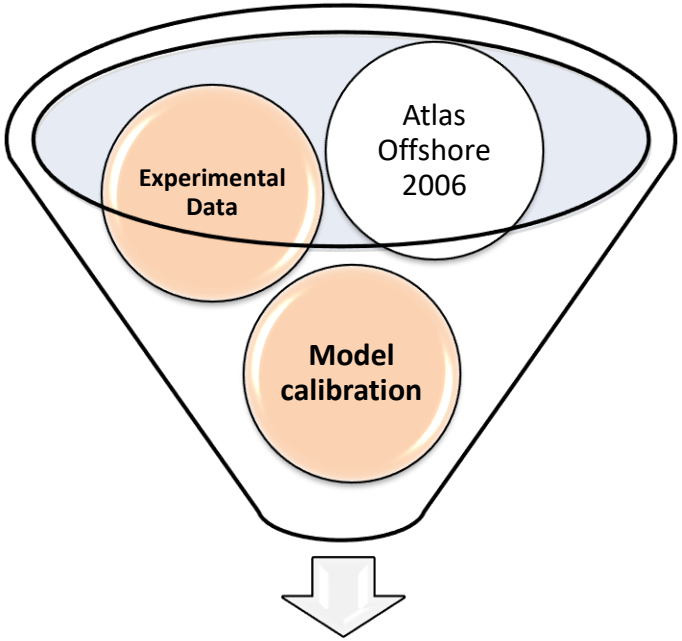
LNEG

Our motivation:

- The first offshore wind Atlas for Portugal was produced in 2006.

- The **improvements** observed in the **numerical simulation field**, the **lack of measurements to validate** the previous Atlas, **required a new offshore wind Atlas** to support the spatial planning of marine energy sources for the maritime area of Continental Portugal.

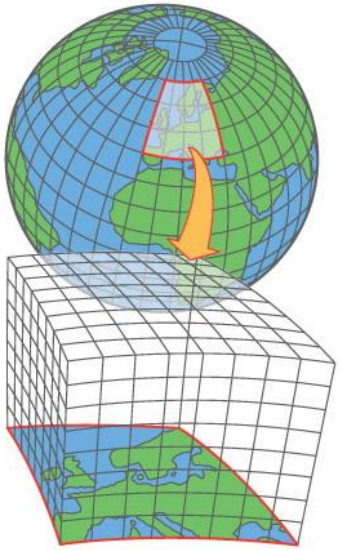
- In **this work presents**:
  1. the **mesoscale model calibration steps**.
  2. a high spatial resolution (1x1 km) **offshore wind resource Atlas for Portugal**



Mesoscale modelling features to improve the wind resource characterization

- *Meteorological boundary and initial conditions*
- *Atmospheric parameterizations*
- *Data assimilation*
- *Simulation restart*

- *Meteorological boundary and initial conditions (IBC)*



Source: www.csc.fi

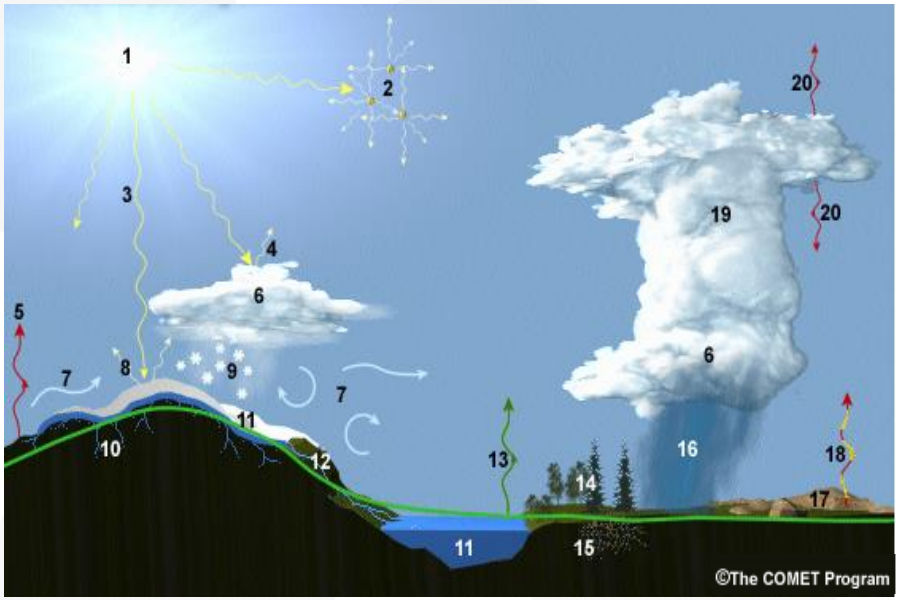
- **Data from global model present low spatial and temporal resolutions for local effects characterization**:
  - Spatial Res.: > 25 km;
  - Temporal Res.: > = 1 h (typically 6 h).

- Data from global models essential for feeding mesoscale models:
  - **Initial and border conditions**

Main characteristics of the most common applied IBC products.

Dataset	Time res. (hours)	Assimilation system	Horizontal res. (Lat. X Lon.)	Vertical levels
NCEP-R2	6	3D-Var	2.50° x 2.50°	28
CFSR	6	3D-Var	0.50° x 0.50°	64
ERA-Interim	6	4D-Var	0.75° x 0.75°	60
GFS	6	3D-Var	0.25° x 0.25°	64
FNL	6	3D-Var	1.00° x 1.00°	52
ERA-5	1	4D-Var	0.28º x 0.28º	72

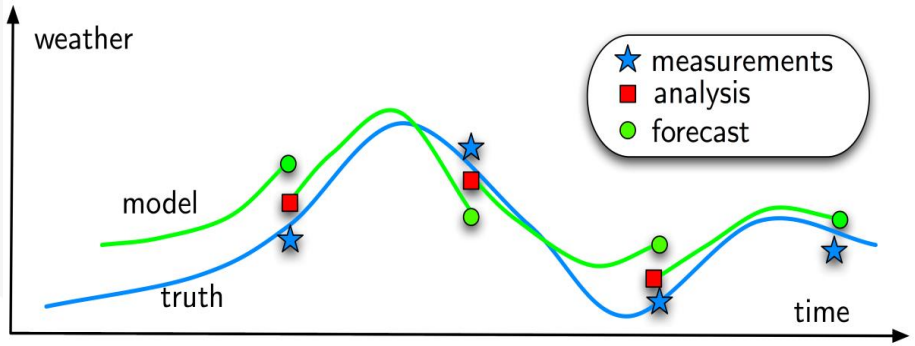
- *Atmospheric parameterizations*



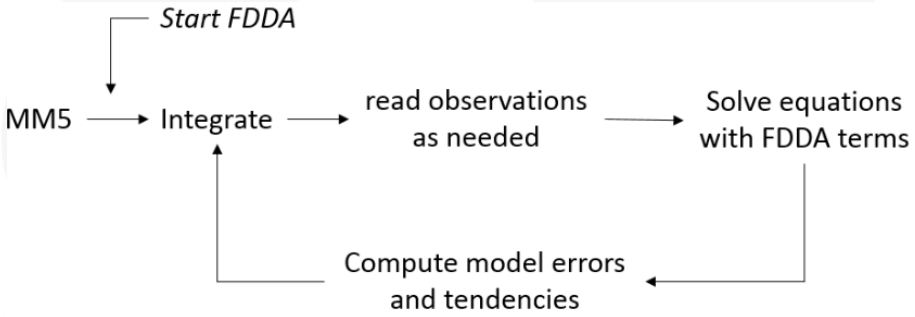
Source: The COMET program (adapted).

- Mesoscale models solve the Navier-Stokes equations.
- **Numerical parameterizations** enable to close the equations using approximations in the simulation to describe the physical processes:
  - *Planetary boundary layer*
  - *Cloud microphysics*
  - *Cumulus*
  - *Radiation processes*
  - *Etc. …*

- *Data assimilation schemes*



Source: pedagotech.inp-toulouse.fr

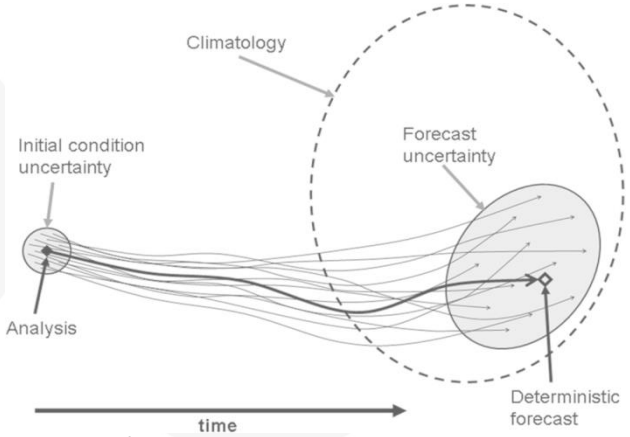


- **Assimilation**: numerical technique that combine observed meteorological data with a "first guest" product derived from the NWP model.
  - Equations and parametrizations of the model assure the atmospheric dynamic consistency;
  - Observations keep the model close to the real conditions compensating the deviations associated with the model physics.

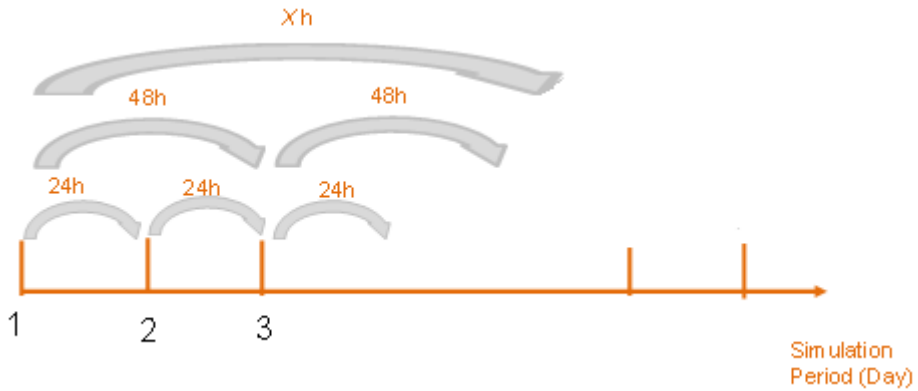
- Most relevant parameters in the assimilation schemes:
  - Influence radius - R;
  - Time window - T;
  - Nudging coefficient (influence in the Navier-Stokes equations) - G.

LNEG

- *Simulations restart*



*Source**

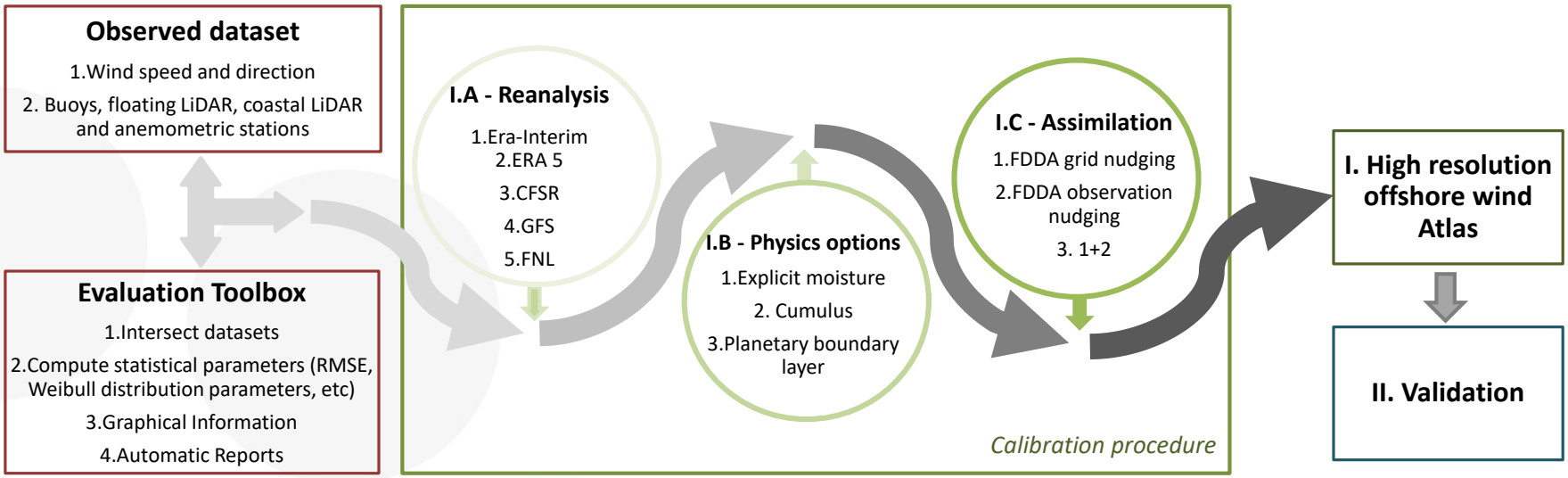


- To avoid errors' propagation during the simulation, a daily restart approach was imposed.

Source: High-impact weather in mid latitudes. (2016). In J. Li, R. Swinbank, R. Grotjahn, & H. Volkert (Eds.), Dynamics and Predictability of Large-Scale, High-Impact Weather and Climate Events (Special Publications of the International Union of Geodesy and Geophysics, pp. 67-130). Cambridge: Cambridge University Press.*

Development of the new offshore wind Atlas: Model calibration - *Step I*

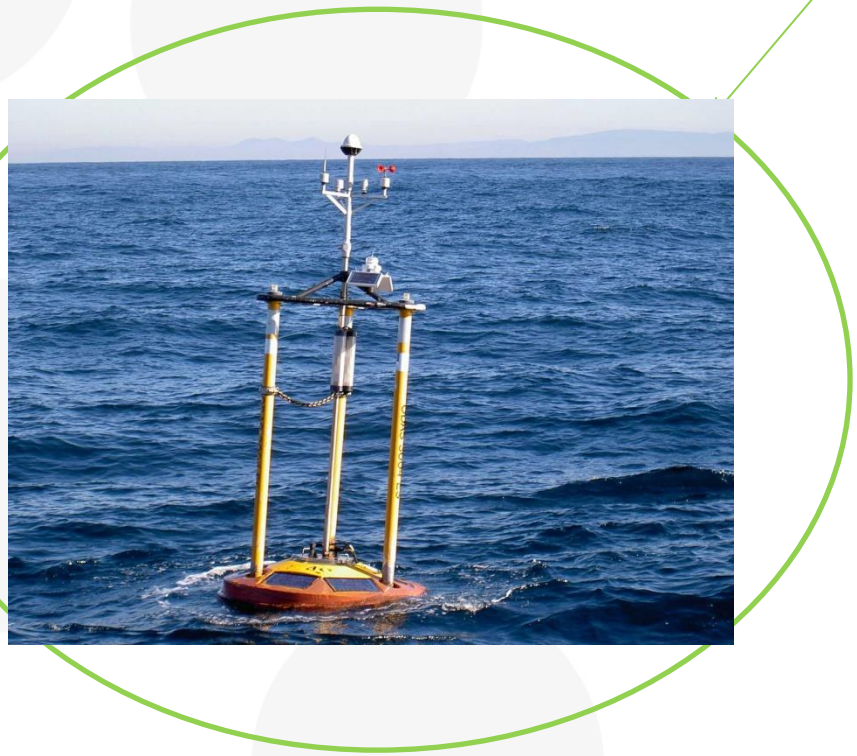
- *Methodology*
- *Data*
- *MM5 model configuration*
- *Results*

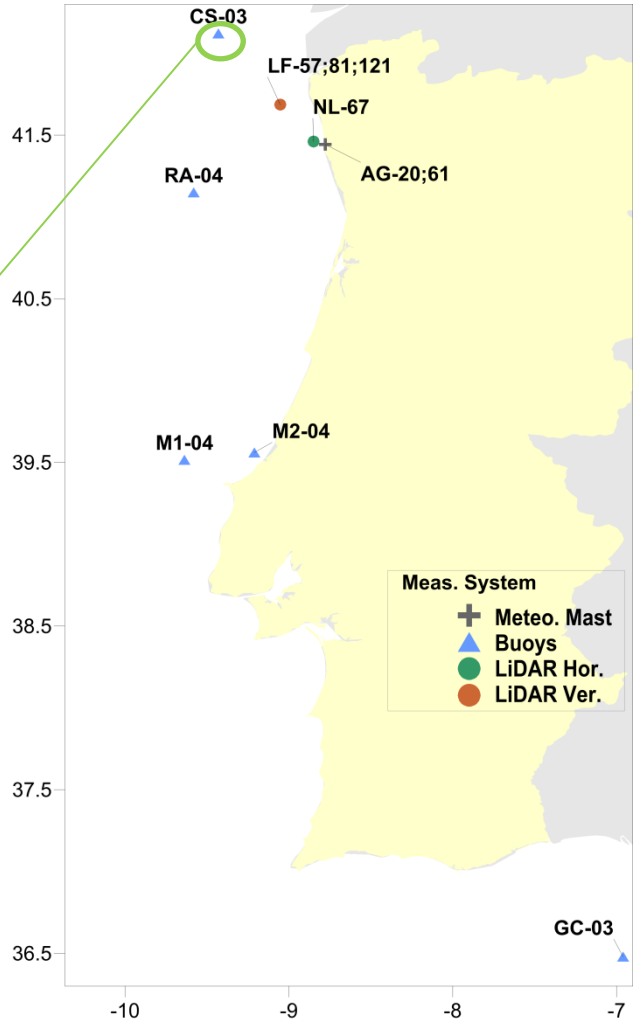


- **Numerical Mesoscale Model** → Fifth-generation Mesoscale Model - **MM5**.
- Evaluation Toolbox → developed to compute the common statistics metrics (*e.g.*, RMSE, bias, Pearson correlation, Weibull distribution parameters, etc.).
- The model calibration is performed through sensitivity tests using the common statistics metrics and hourly simulated/observational data.

Data – Calibration step

- Observed data used during the calibration step:
  - Buoys publicly available (Instituto Hidrográfico, Puertos del Estado;





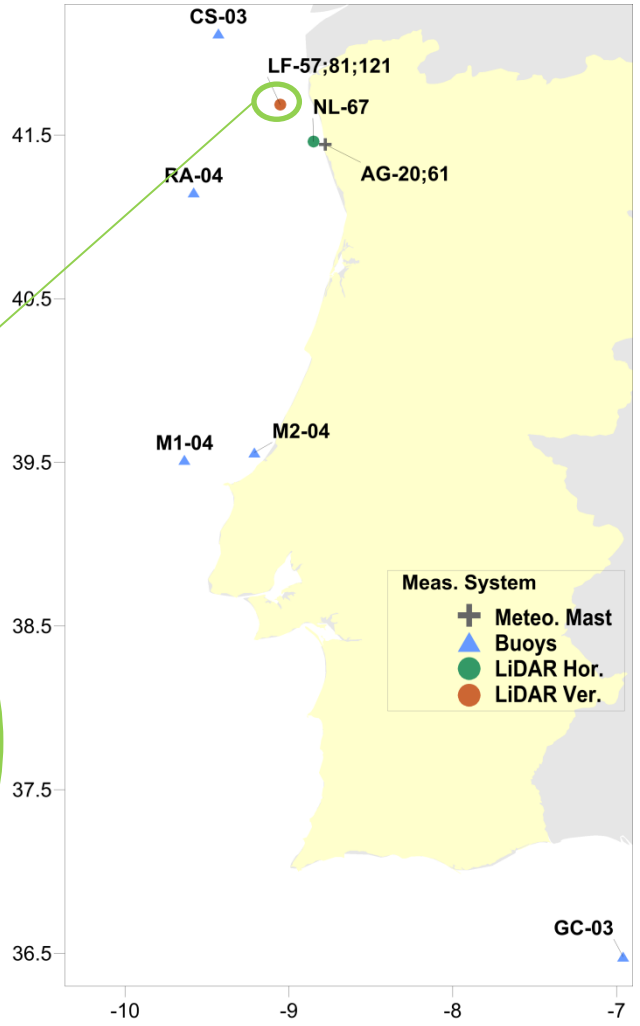
Data – Calibration step

- Observed data used during the calibration step:
  - LNEG database (e.g., FP7 NORSEWind and DEMOWFloat);
  - ✓ Horizontal LiDAR installed at the top of WindFloat wind turbine

Fig. 6. Picture from the WindFloat system (picture extracted from: www.demowfloat.eu - accessed on 19th July 2015).

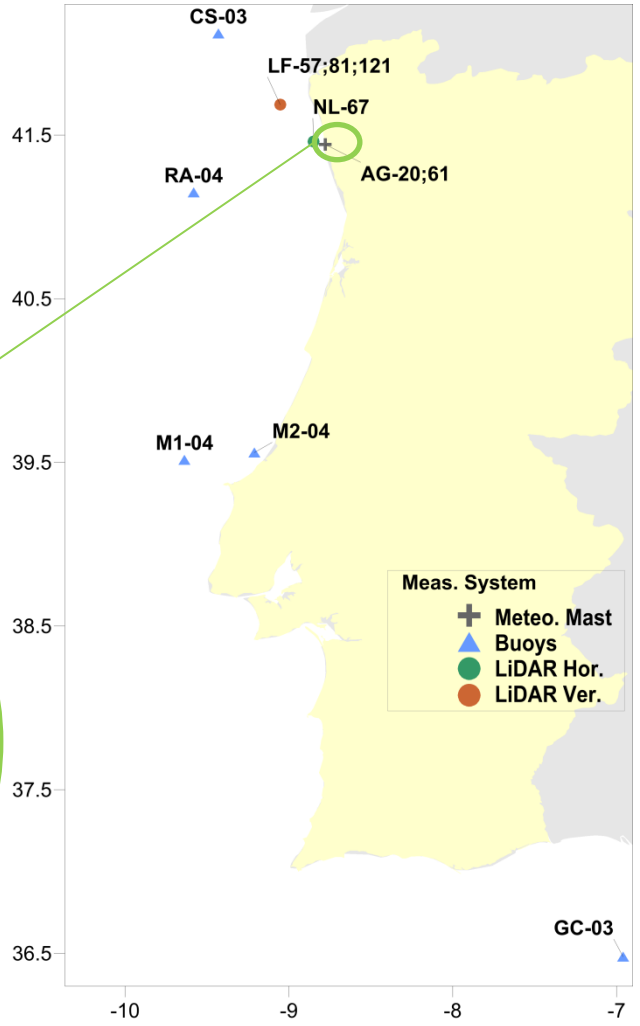
Data – Calibration step

- Observed data used during the calibration step:
  - LNEG database (e.g., FP7 NORSEWind and DEMOWFloat);
  - ✓ Floating LiDAR



Data – Calibration step

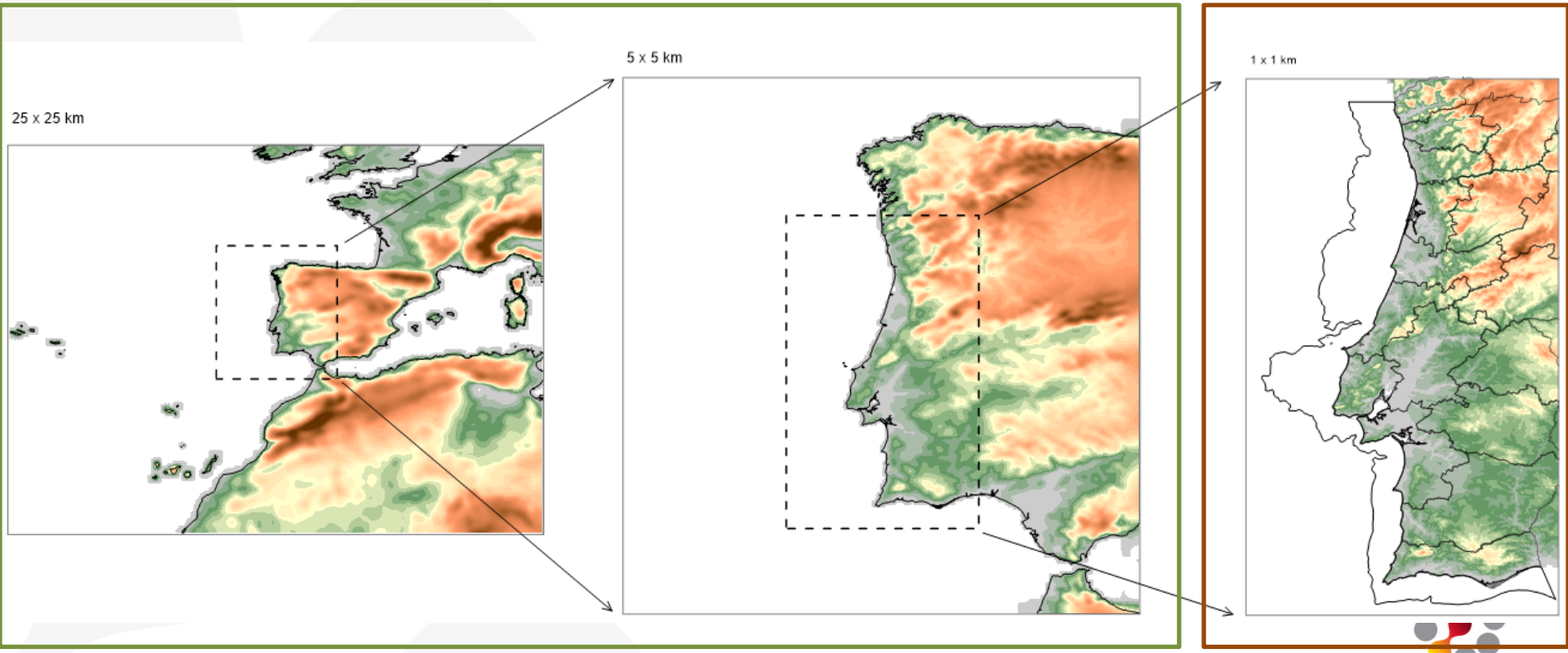
- Observed data used during the calibration step:
  - LNEG database (e.g., FP7 NORSEWind and DEMOWFloat);
  - ✓ Meteorological mast installed near the shore



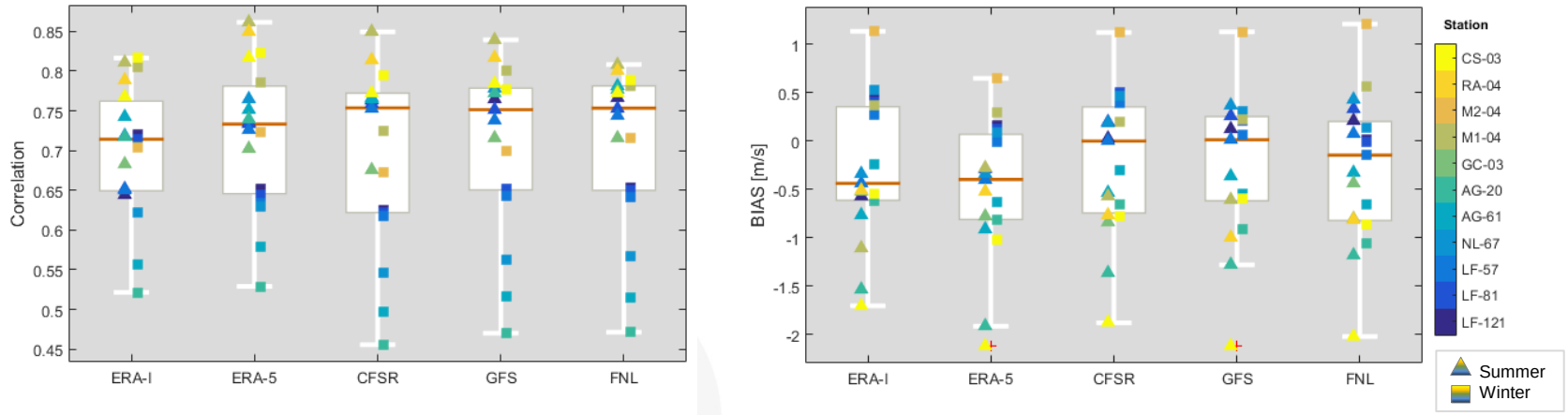
Data – Calibration step

- **Assimilation data:**
  - **Satellite → *Global blended ocean wind – scatterometer* ASCAT e OSCAT.**
    - Spatial resolution - 0.25º; Temporal resolution 6 hours.
    - Wind components.
  - **ERA5 data with *ECMWF forecasts***
    - Spatial resolution - 0.28º; Temporal resolution 1 hour.
    - All relevant meteorological parameters (U, V, T, P, etc) for several vertical levels.
- Calibration period:
  - **Summer**: 01-08-2014 a 01-09-2014
  - **Winter**: 29-12-2014 a 29-01-2015

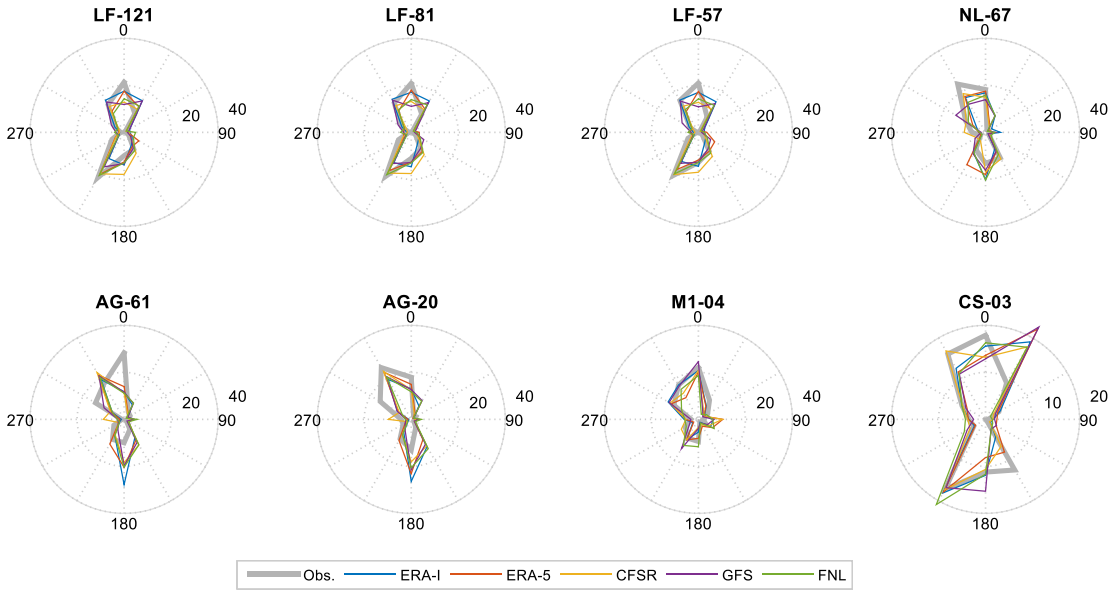
- **3 domains using a one-way nesting technique.**
- **Spatial resolution** : 25x25km, 5x5km e 1x1km (until 300 m bathymetric).
- Simulations were configured *i)* to restart every day, *i.e.*, runs continuously only 24 hours, and *ii*) for recording data every hour.



- **I.A** - Identification of the **most adequate meteorological initial and boundary conditions**
  - *5 products were tested: FNL, ERA-Interim, CFSR, GFS e ERA-5.*

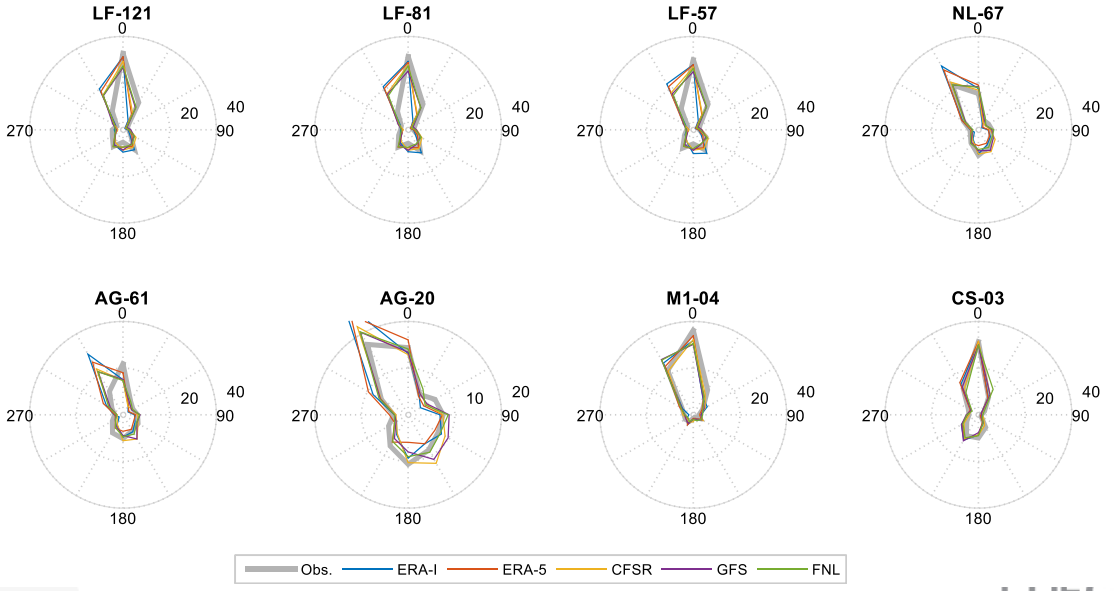


- Overall, the recent **ERA-5 (ECMWF) product presents the best performance** in the statistical parameters analysed.

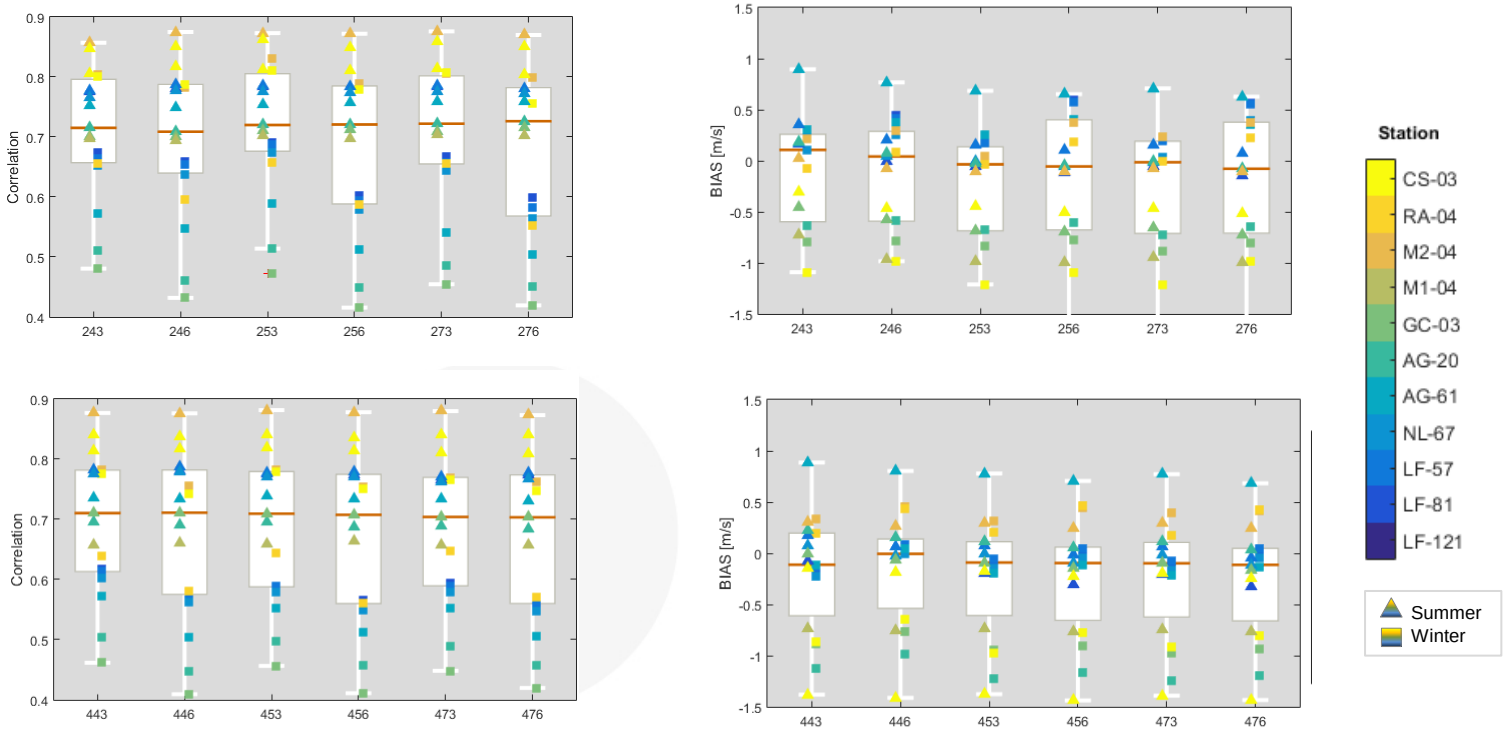


- **Power density rose**

- **Wind rose**

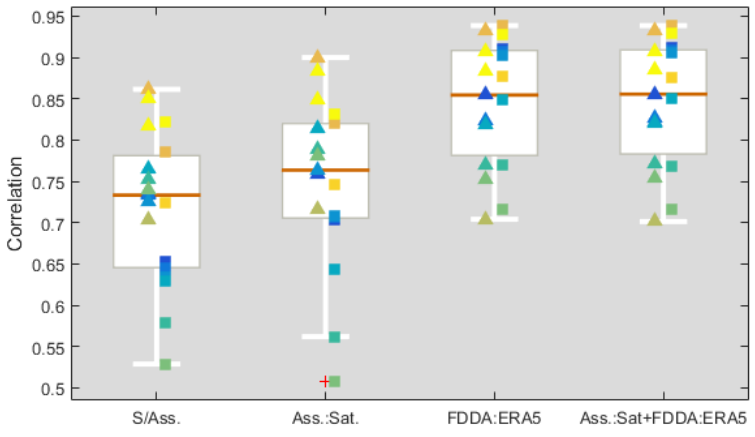


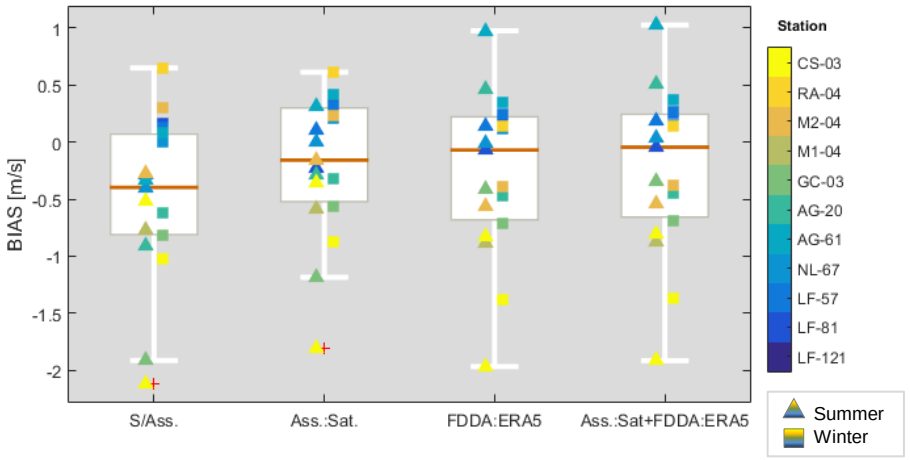
- **I.B** - Identification of the **most adequate physical parameterizations**:
  - *27 different set of parameterizations were tested: Microphysics - IMPHYS (3), PBL - IBLTYP (3), and cumulus- IUCUPA (3).*



- The sensitivity tests for the atmospheric parameterization showed **small differences among the different options tested.**

- **I.C** - Identification of the **most adequate assimilation scheme and data**:
  - *Several sensitivity tests (e.g., nudging, obs-FDDA) were implemented to identify the most adequate assimilation scheme, parameters (G, T and R) and dataset.*

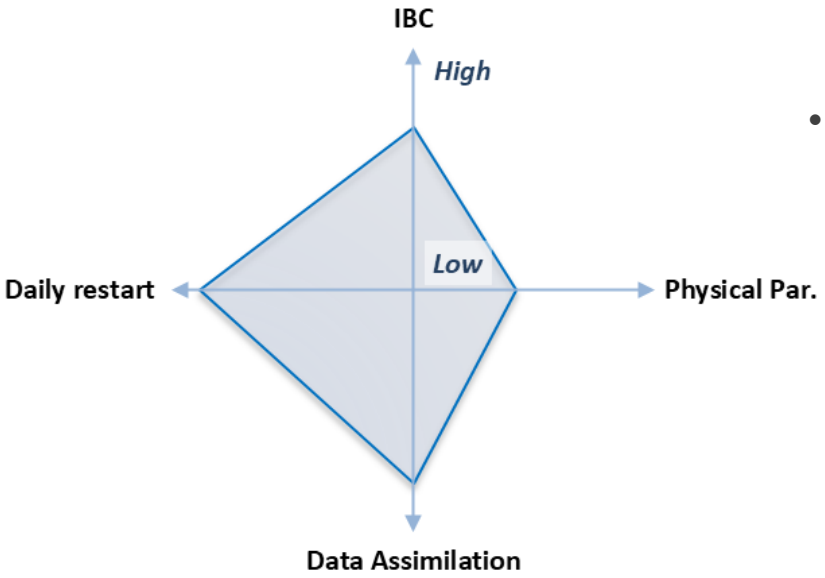




- Using the **four-dimensional data assimilation (FDDA) scheme significant improvements were found.**

- **Best performance** was achieved with the **data assimilation based on information inferred by satellite** in the ocean **coupled with data from ECMWF reanalysis ERA-5** project.

- More than 100 sensitivity tests were performed using the MM5 model.



- **The highest improvements** in the calibration results were **associate to:**
  - **Daily restart** of the model → prevents the errors propagations during the simulations;
  - **Data assimilation** schemes.

- Based on the previous findings → **long term simulations were performed to obtain the new offshore wind Atlas for Portugal with a spatial resolution of 1km**:
  - Simulated period : 01.01.2015 – 31.06.2018

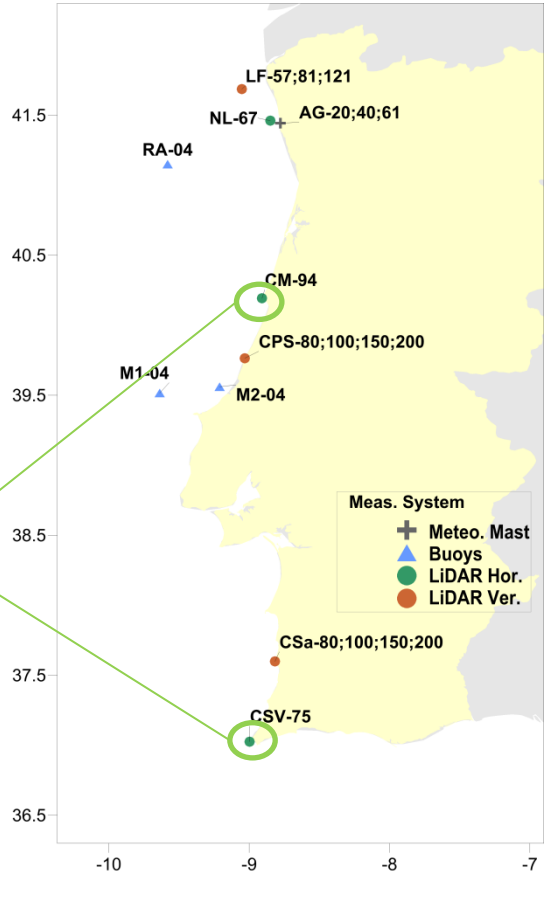
New offshore wind Atlas: Atlas Validation - *Step II*

- *Data*
- *Results: validation performance and the new offshore wind Atlas*

Data – Validation step

- Short-term experimental measurement campaigns took place to validate the new offshore wind Atlas.
- These campaigns were based on Light Detection and Ranging (LiDAR) systems:

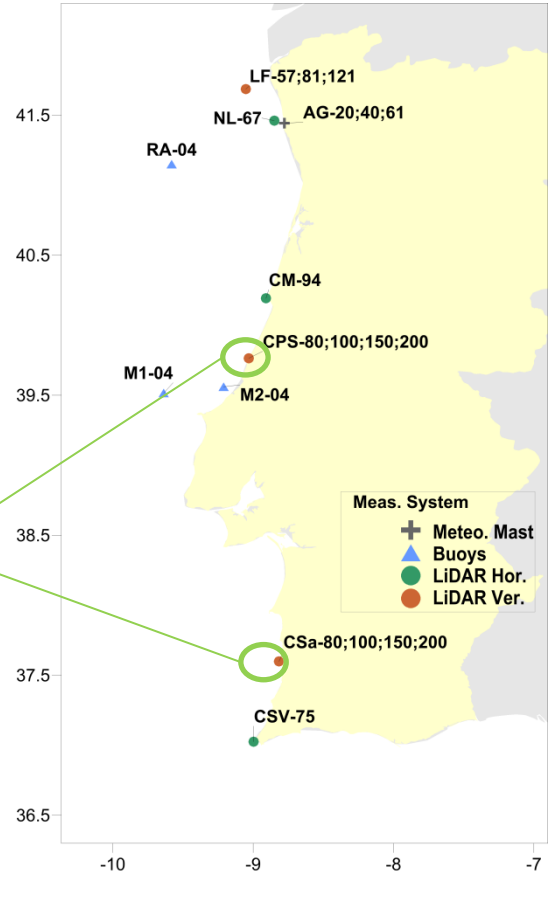
  ➢ **Horizontal LiDAR system:**



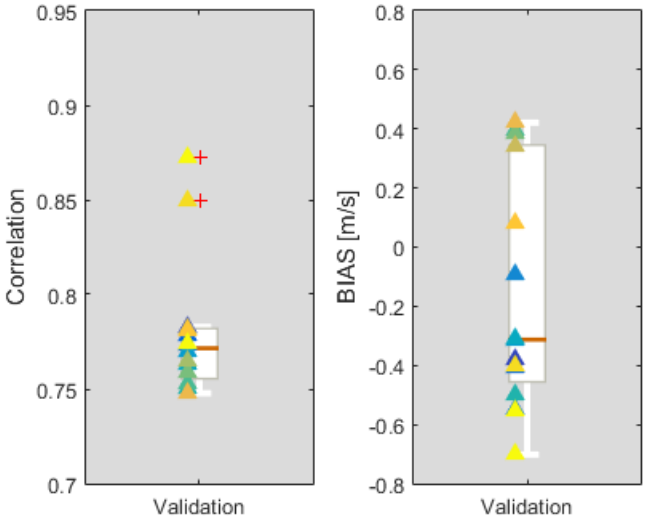
Data – Validation step

- Short-term experimental measurement campaigns took place to validate the new offshore wind Atlas.
- These campaigns were based on Light Detection and Ranging (LiDAR) systems:

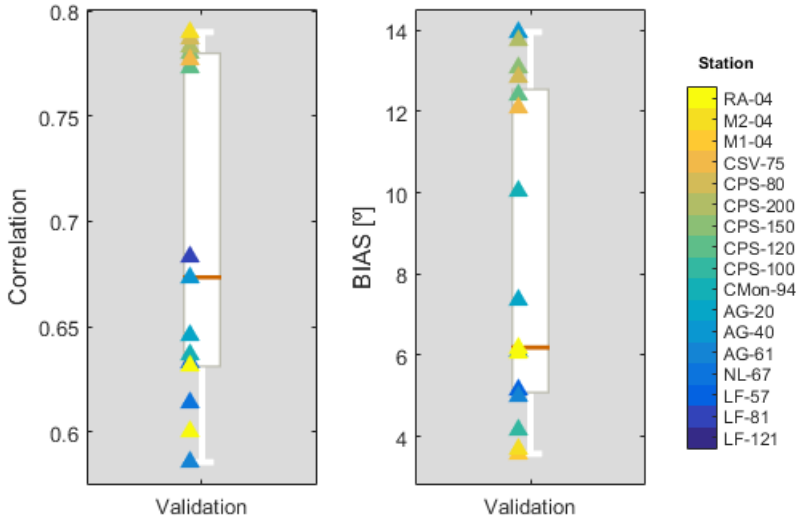
  ➢ **Vertical LiDAR system:**



➢ Wind speed results

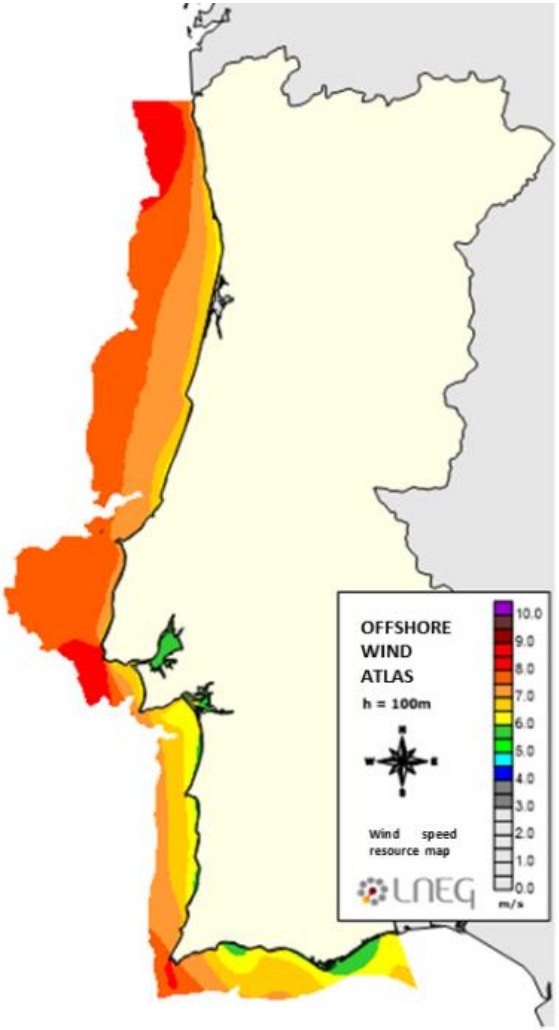


➢ Wind direction results

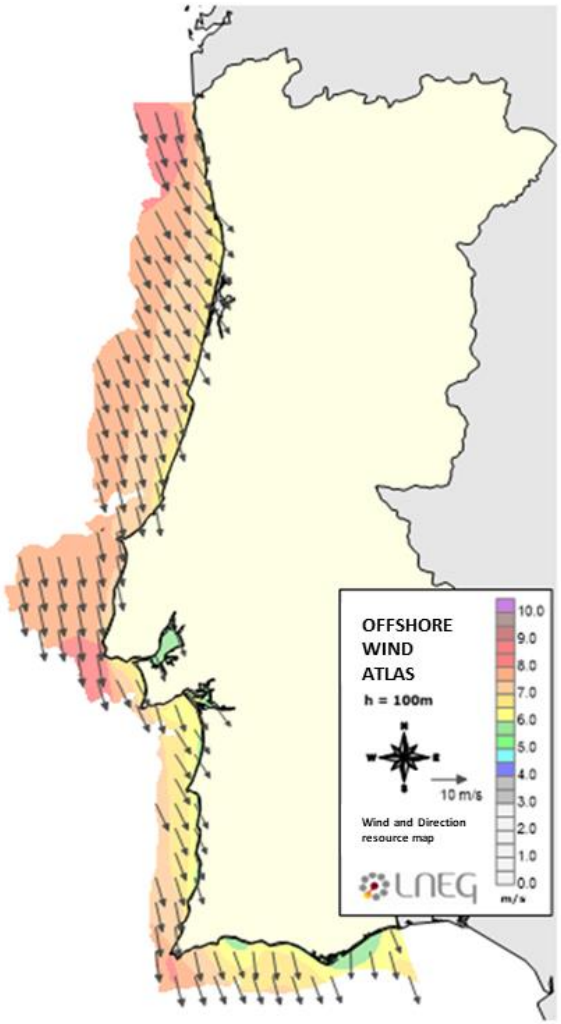


- The **average bias error is only -0.14 m/s**, while the median value is -0.29 m/s.
  - Errors showed non-dependency from the measurement height → stratification of the atmosphere was correctly simulated;
- Average wind speed correlation is 0.79, although some measurement points show a correlation of nearly 0.90.
- **Average wind direction bias error is always above 15º**. For some stations, the correlation is only 0.6.

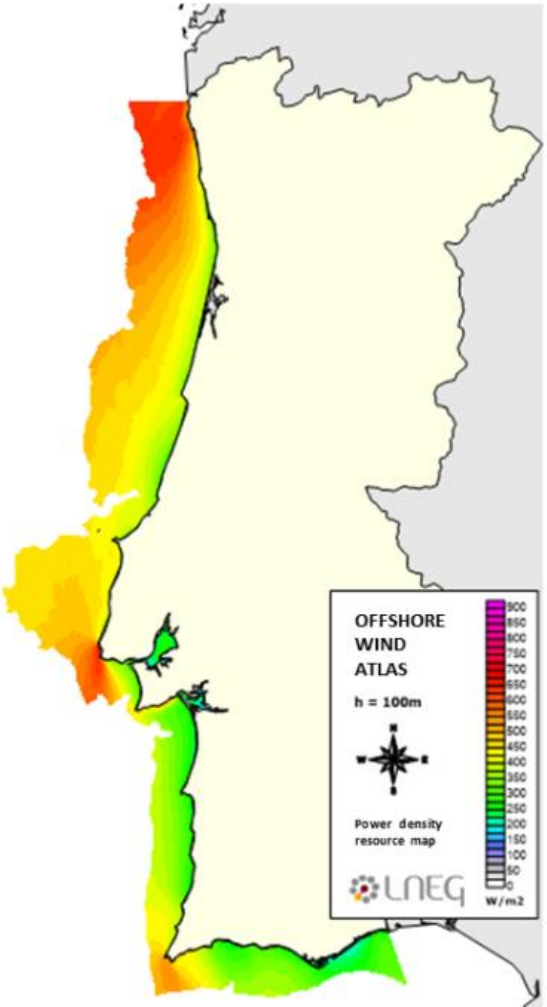
- **Wind speed map**



- **Wind direction map**



- **Power density map**



LNEG

Final remarks

- The calibration procedures and the new offshore wind Atlas for Portugal with a spatial resolution of 1x1km to adequately describe the wind phenomena over the sea and in the cross-border sea/land areas was presented.

- Results show that the **calibration procedure is a crucial step to improve the wind speed and direction characterization.** The **most meaningful improvement was associated with the data assimilation procedure with the observational four-dimensional data assimilation – FDDA, the simulation restart followed by the IBC dataset used**.

- On average, the new Atlas shows a bias error equal to -0.14 m/s, and a correlation of 0.79.

- Although further research is required to enable its full validation, the adoption of assimilation procedures coupled with the state of art of meteorological IBC presents a promising improvement in the accuracy of the wind resource assessment, especially, at regions where observed wind data are not available.

LNEG

MarinePlan – Platform for technical and economic planning of systems for renewable marine energy exploitation

This work was co-financed by the Operational Program for Sustainability and Efficiency in the Use of Resources (POSEUR) through Portugal 2020 and the Cohesion Fund (OffshorePlan Project - POSEUR - 01-1001-FC-000007)

LNEG

Objetive: Provide an economic technical planning platform to support the development of marine renewable energy projects.

Why?

- Spatial variability of renewable resources on the Portuguese coast is a reality;
- Technology maturity is evolving - it is necessary to monitor;
- Decision on technologies to be installed - Economic indicators enable their hierarchy and decision making
- Organized planning for the installation of offshore renewable energy is necessary - national commitments (NCEP2030, RCN2050)

LNEG

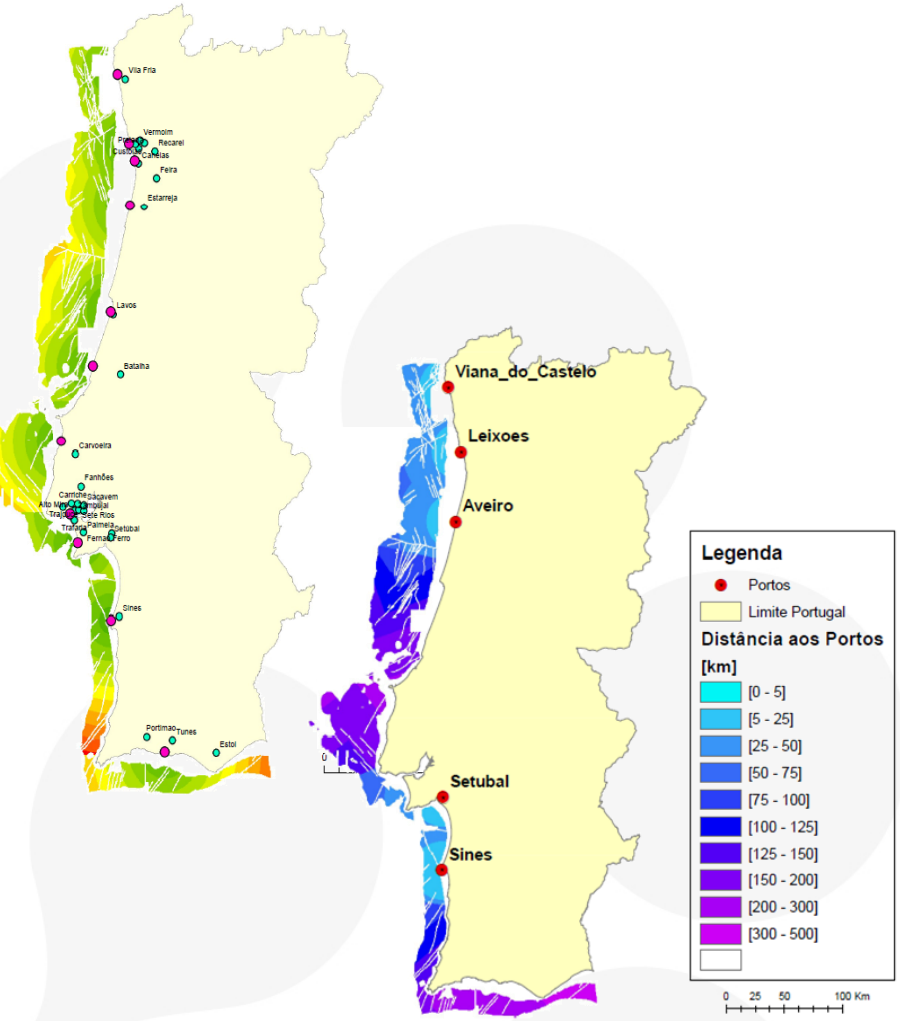
MarinePlan enables to:

- Carry out an economic analysis of investments in renewable offshore systems taking into account the spatial variability of renewable resources on the Portuguese Coast;

- Monitor and reflect the evolution and maturity of technologies (CAPEX, OPEX and DECEX).

- Obtain maps of Economic Indicators off the Portuguese coast (LCOE, VAL, TIR, Payback) for different technologies, enabling their hierarchy;

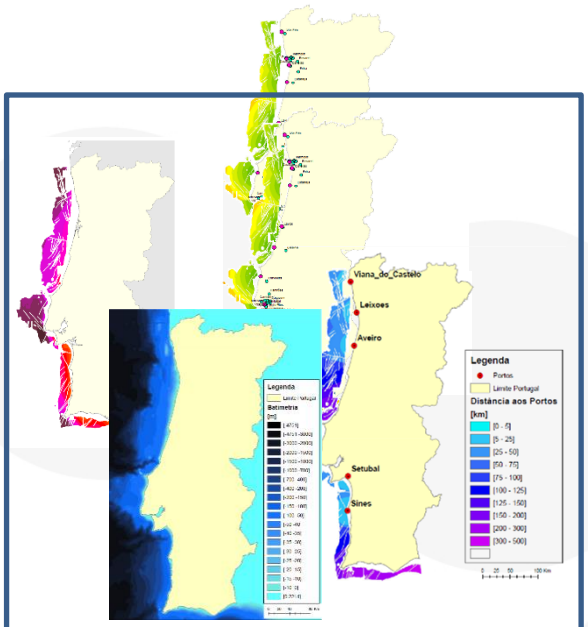
Input data:



- Mapping of offshore renewable resources according to the technology
- Bathymetry mapping;
- Ports Location;
- Interconnection points on the Portuguese coast near substations of the National Transport Network (NTN);
- Matrix of estimated costs of interconnection cables according to the length and power to be transmitted.

LNEG

Methodology and data flux



Input data:

- Maps (energy resource, bathymetry, ports location, National Transport Network,…)
- Investment Costs, O&M costs, …

$$VAL = -I_0 + \sum_{k=1}^{n} \frac{FC_k}{(1+d)^k}$$

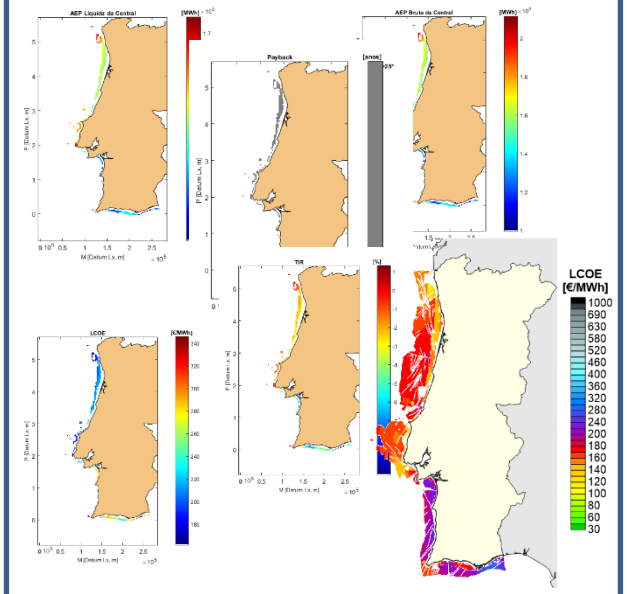
$$\sum_{k=1}^{Tr} \frac{FC_k}{(1+d)^k} \geq I_0$$

$$LCOE = \frac{\sum_{k=1}^{n} \frac{CA_k}{(1+d)^k}}{\sum_{k=1}^{n} \frac{ECR_k}{(1+d)^k}} \times 1000$$

$$-I_0 + \sum_{k=1}^{n} \frac{FC_k}{(1+TIR)^k} = 0$$

Economic indicators:

- IRR
- NPV
- LCOE
- Payback



Results:

- Maps or single values for the economic indicators
- Hierarchy of technologies

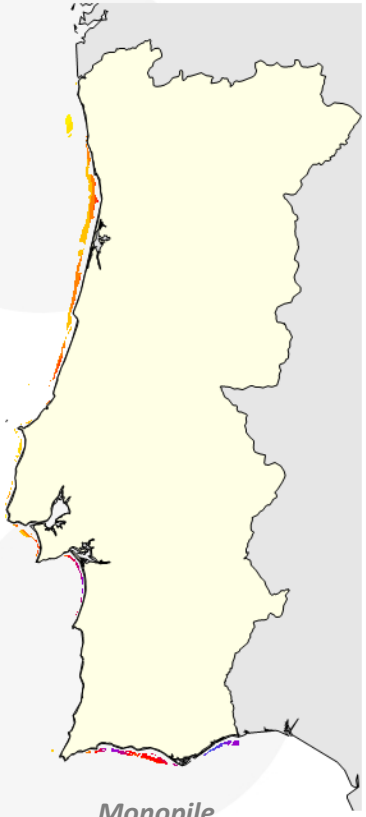
MarinePlan's results – economic indicators

- Indicators can be obtained for a specific renewable offshore plant, according to two different modes of application:
  - i) offshore mapping considering that the renewable plant can be placed in any location in the exclusive economic zone, respecting the restrictions and constraints applicable to the technology of the plant to be installed;
  - ii) isolated point dissociated from any spatial location where the values of the input parameters that would be implicit to its geographic location are indicated by the user.
- It is also possible through the tool provided to analyze the hierarchy of projects created by the user according to each economic indicator considering the spatial results obtained in i).
- When applicable and available, the values suggested in the tool, should be understood, exclusively, as indicative and, in no case, used as a reference.

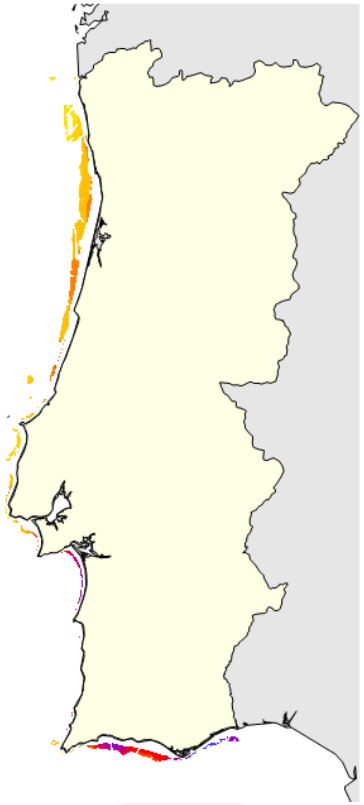
LNEG

Results

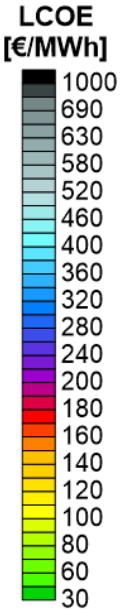
Levelized Cost of Energy (LCOE); Technology : (Bottom Fixed) Offshore Wind Energy

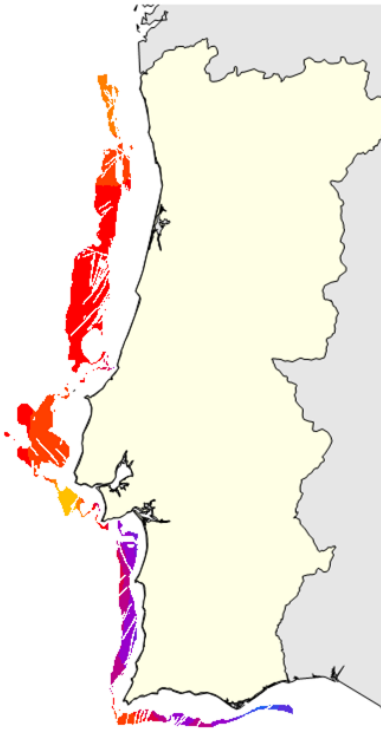


Monopile
6.15 MW.

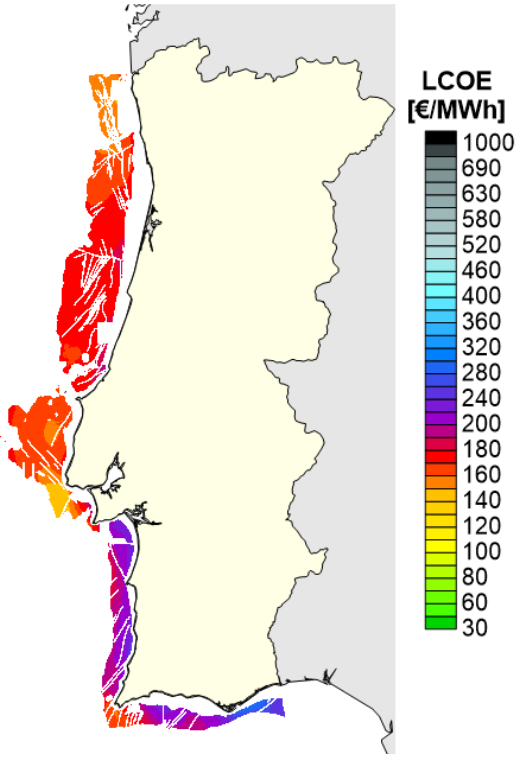


Jacket
6.15 MW.





Hywind
6 MW.

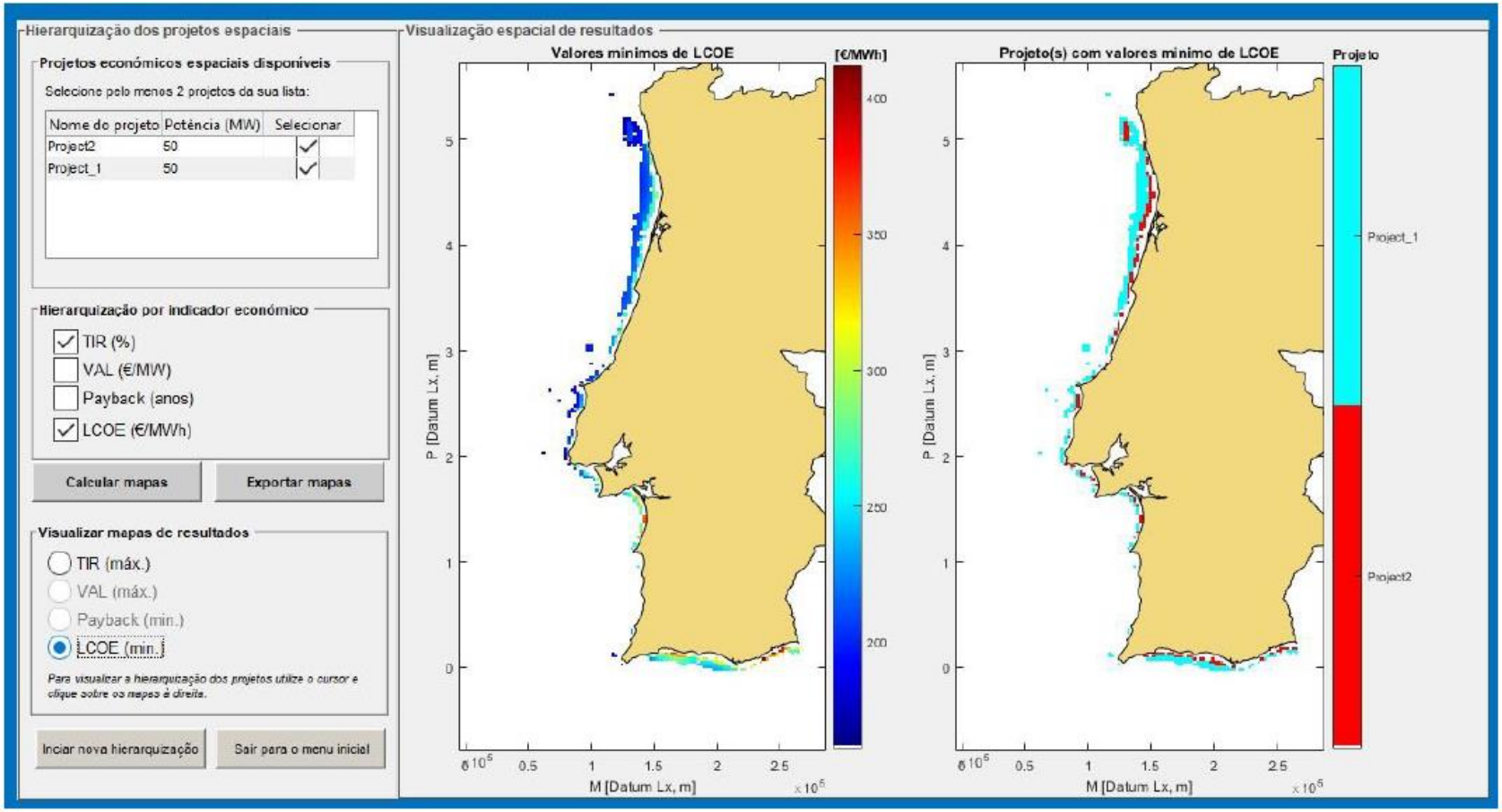


Windfloat
8 MW.

LNEG

Results

Hierarchy of technologies



Summary

- The spatial distribution of economic indicators and the analysis of the resulting maps allows the **identification and delimitation of offshore areas with more encouraging economic results** for the installation of different technological types (“manufacturer insensitive”).

- The developed platform is **dynamic and allows the alteration and introduction of input values** (technical and economic) allowing an analysis (and scenario) of the cost evolution of the different modeled technological types.

- It is possible to analyze the economic viability of the investment for **different remuneration scenarios.**

- The hierarchy of the LCOE allows the **identification of the most appropriate technology for each location** / region under analysis.

- The MarinePlan Platform is publicly accessible and available on the OffshorePlan project page (Portuguese version).

LNEG

www.lneg.pt

- **Further details:**

Tool available at: https://offshoreplan.lneg.pt/

A. Couto, J. Silva, P. Costa, D. Santos, T. Simões, and A. Estanqueiro, 'Towards a high-resolution offshore wind Atlas - The Portuguese Case', *J. Phys. Conf. Ser.*, vol. 1356, p. 012029, Oct. 2019. Available at: https://iopscience.iop.org/article/10.1088/1742-6596/1356/1/012029

- **Contacts:**

teresa.simoes@lneg.pt
antonio.couto@lneg.pt
ana.estanqueiro@lneg.pt

REPÚBLICA PORTUGUESA
AMBIENTE E TRANSIÇÃO ENERGÉTICA