REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: Italy

Principal Investigator[1]: Bonanno Riccardo

Affiliation: RSE S.p.A. Ricerca sul Sistema Energetico

Address: V Rubattino, 54 - 20134 Milano, IT

Other researchers: Collino Elena, Sperati Simone, Viterbo Francesca, Lacavalla Matteo

………

Project Title: WRF-based high resolution simulations to improve the resilience of the Italian Energy System

………

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ………….	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2025	
Would you accept support for 1 year only, if necessary?	YES ☐	NO X

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	50000000	50000000	50000000
Accumulated data storage (total archive volume)[2]	[GB]	50000	50000	50000

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Principal Investigator: Bonanno Riccardo

Project Title: WRF-based high resolution simulations to improve the resilience of the Italian Energy System

Extended abstract

Introduction and motivation

The growing penetration of renewables on the one hand and the increase of extreme weather events on the other, has strengthened the need of reliable weather information to better manage and design the electrical energy system. A deep transition of the Italian Energy system is undergoing, with consistent economic investments aimed at improving the resilience of the transmission and distribution networks. This is in response to the non-programmability of some renewable energy sources, such as wind and solar, and to address the general increase in energy demand, especially during summer, due to cooling demand, linked to prolonged heat waves and the increasing frequency and intensity of extreme weather events. As a matter of fact, Italy is expected to be particularly affected by climate change according to many previous studies, such as the one by Spano et al [1]. To meet the goals foreseen by the European Union (EU) Green Deal, by means of the application of the "Fit for 55" package [1], Italy intends to expand the capacity of the non-programmable energy resources, including the increase of wind capacity from 12 GW in 2022 to 28 GW by 2030, according to the Integrated National Energy and Climate Plan [3]. In this context, to efficiently plan new installations high resolution meteorological reanalyses are fundamental. They support in the evaluation of the potential of each region of the country in terms of resources and to successfully integrate information on environmental and social restrictions. This is particularly important in areas characterized by complex orography, where small-scale physical processes play an important role in triggering intense and localized events.

To answer these needs, the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) instructed Ricerca sul Sistema Energetico (RSE) S.p.A. to develop reanalysis products which can provide a common meteorological dataset for the energy sector. From this original assignment, in 2019, the MEteorological Reanalysis Italian DAtaset (MERIDA) and the MERIDA Optimal Interpolation (OI) dataset were born, with 7 km spatial resolution and 1 h time resolution over Italy. The constant push toward higher resolutions and toward the development of new datasets gave birth to another additional dataset: the Atlante EOLico ItaliANo (AEOLIAN) dataset, a wind atlas at 1.3 km that offers promising results for representing high resolution wind speeds over the Italian territory [4]. In the process, another fully physically based reanalysis, at higher resolution than MERIDA, with 4 km resolution and updated parameterizations, called MERIDA High-RESolution (HRES), was born. MERIDA HRES, in fact, gave the Initial Conditions (IC) and Boundary Conditions (BC) for the AEOLIAN dynamical downscaling.

The aforementioned datasets are based on WRF simulations and have been configured and optimized for specific applications within the Italian Energy System, aimed at improving the resilience of the electrical system, particularly, with respect to wet snow and extreme precipitation events (MERIDA) and at supporting the planning of renewables (MERIDA HRES and AEOLIAN).

At present, other challenges also need to be addressed to make the energy system more resilient. These include stress on underground electrical lines due to prolonged heat waves and peaks in energy demand, local and extensive floods and landslides caused by intense precipitation, which are exacerbated by strong urbanisation. In-cloud icing is another dangerous hazard for overhead electrical lines and infrastructures.

It is therefore essential to perform many in-depth analyses to detect the ideal configuration of WRF for the Italian territory, in terms of spatial and temporal resolution and parametrizations, due to the complex orography and the variability of type and use of soil, according to multiple applications. In particular, in this project, it is intended to investigate the response to atmospheric forcings in urban environments, which significantly differs from surrounding areas, due to the distinct characteristics of urbanized areas compared to adjacent rural areas. These studies, performed in hindcast-mode, will provide a solid foundation for evaluating the feasibility of developing a new high-resolution reanalysis for the Italian territory. Once a good parameterization is found, this setting could also be used to run WRF in forecast mode, allowing the possibility of operational forecasts that can be applied for multiple variables of interests with many possible benefits.

While exploring the ideal configuration of WRF, in this project, we mean to extend the existing RSE reanalyses products, and particularly the dynamical downscaling of the AEOLIAN dataset to the most recent past. An important requirement for regional reanalysis products is that they are a continuous dataset, spanning to multiple years, to allow bias correction and trend analyses and that they are constantly updated with the last available observations until present, to include the most extreme events that happened in the recent past.

As far as the extension of the AEOLIAN dataset, the target is to extend it at least until 2024. AEOLIAN was developed by RSE, in collaboration with the National Center of Atmospheric Research (NCAR) and consists of a 30-year reanalysis dataset from 1989 to 2019 of wind intensity and direction, where the time span from 2015 to 2019 is derived from a 2 grid dynamical downscaling of the ERA5 global reanalyses and the MERIDA HRES reanalyses, while the period from 1989 to 2014 derives from the application of a statistical downscaling of the MERIDA HRES reanalysis, based on the Analog Ensemble Technique [6]. The choice of extending the dataset for the first 25years by means of a statistical downscaling mainly depends on the goal of reducing computational effort while preserving the quality of the final dataset. Even though the dataset already covers a time span of 30 years, further extension to recent years is beneficial both to improve the robustness of the derived statical information and to account for ongoing changes in the local climate, also including extreme events. On this regard, a late request for a special project has been submitted at the beginning of June 2024 to simulate the years 2020 and 2021. An even longer dataset enables to choose different historical reference periods and to study changes in frequency and intensity of wind-related weather events, such as calm situations or storms, which affect the wind production and the security of civil constructions, including electrical structures and overhead lines. The dataset could also be used to evaluate or train AI-based meteorological forecasting system specifically designed for wind forecasting.

Scientific plan

As far as the objective to design an optimized WRF configuration for Italy, both for forecasting and reanalyses development, several sensitivity analyses are going to be conducted, trying different model settings. The main goal is to identify a configuration that is able to well represent together some of the main variables of interest for the electrical-energy system (i.e precipitation, surface temperature, wind, irradiance and soil properties). It is expected that the result will derive from a compromise among different optimized configurations obtained for each specific variables, being aware that, very often, optimizing the outcomes on one particular variable, performances are degrading on some other process. As a consequence, a particular focus would be given to investigate the capabilities of the WRF model to reproduce the physical processes at 1.3 km resolution, facing the different challenges of high-resolution models related to complex topography and coastal processes (especially when crossing the boundary of explicit representation of convection). The workplan consists in the following steps: to select a set of extreme weather events of interest for the electro-energy system such as extreme synoptic and convective precipitations events, extreme wind storms, urban heat waves, favourable weather conditions for the spread of catastrophic wildfires and significant in-cloud icing events, to run several hindcast simulations trying different physic options and settings to explore the sensitivity and the capabilities of the model to reproduce these events. In particular, we are going to investigate the change of performances with different WRF model versions (e.g WRF v3.9 generally used for the actual reanalyses and operational forecast runs in RSE and WRF v4.5 and/or higher) and multiple combinations of physics settings to represent heat and moist fluxes and PBL interaction, together with microphysics schemes. In addition to that, for wildfire, urban and hydro-meteorological events the influence of different soil type and land covers is going to be explored, to better represent the complexity of the soil and the influence of that on the outputs of the model.

In order to do that, several runs are going to be performed, comparing the outputs of the simulations with the available observations to evaluate the performances.

Finally, a comprehensive analysis of the results will be performed to produce a road map for users of WRF-ARW on the Italian territory and evaluate the opportunity of producing a new high-resolution reanalysis supporting the improvement of the Italian energy system resilience.

As far as the goal of extending the New Italian Wind Atlas the working setup has been already defined and tested at the ECMWF's AC server. The simulations consist of WRF3.9 runs, nested on the ERA5 global reanalysis fields using two grids, as shown in Figure 1:

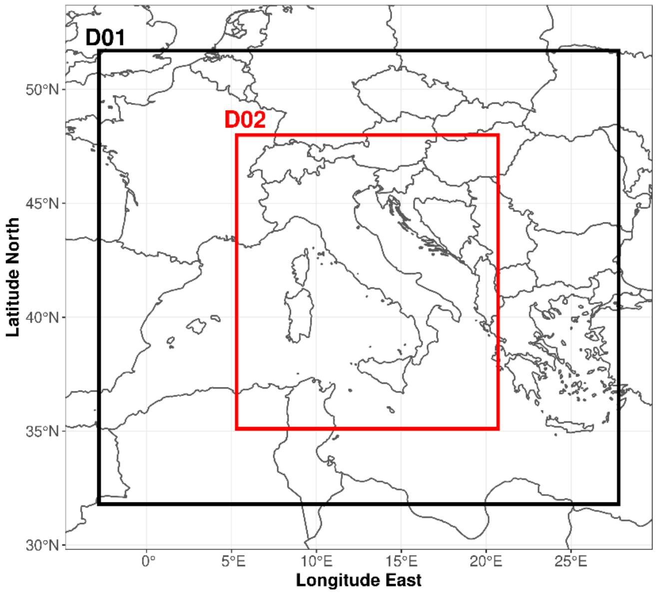

Figure 1 WRF computational domains. D02 is the finer, 1.33 km grid nested on the coarser, 4 km grid (D01).

The chosen configuration of WRF has been set after a thorough analysis of various case studies on the Italian territory [7]. In particular, to enhance the reconstruction of WRF's 10-m wind, which generally shows positive bias in the literature [8], a surface drag parameterization option has been activated [8]. Furthermore, vertical resolution in the Planetary Boundary Layer (PBL) has been increased from the standard one in WRF by defining more levels up to 500 m asl/agl.

An observational nudging, based on 300 stations at 10 m heigh, homogeneously distributed across the Italian territory, complete the model suite.

The model runs are all initialized at 12 UTC every two days for the entire period to reconstruct with a temporal horizon of 60 hours, discarding the first 12 hours as a spin-up time. Each run is then concatenated with the next one at 00 UTC.

Justification of the computer resources requested

Regarding the goal of defining a suitable configuration of WRF at high resolution for the whole Italian Country, the request for computational resources can be estimated considering the ensemble of simulations at high resolution needed to test multiple options and configurations for a consistent number of test cases. It is expected that an amount of 70-80 millions of SBU will be necessary with a disk storage of about 55 TB. This represents an approximate estimation since the effective computational cost will depend on physics options selected, on the compiler, on the WRF compilation options, on the adopted parallel libraries, etc..

As far as concerns the proposal of extending AEOLIAN, tests carried out at the ECMWF's AC server allowed estimating the required resources for this project as follows:

- A single, 2-day WRF run submitted as a parallel job requires about 125,000 SBU
- 550 runs are required to reconstruct the years from 2022 to 2024
- Each run requires a disk storage of about 105 GB after cleaning of unnecessary files.

This results in a total amount of requested resources of 150M SBU and 150 TB for the 3-year project.

Technical characteristics of the code to be used

The required codes for this project are the WRF ARW model v3.9, which has been already installed on the ECMWF's AC server and the WRF model v4.5 and/or higher. The scripts to prepare the input files and launch the simulations are developed in R language.

References

1. Spano D, Mereu V, Bacciu V et al (2020) Analisi del rischio. I cambiamenti climatici in Italia, Lecce: Fondazione CMCC– Centro Euro-Mediterraneo sui Cambiamenti Climatici, 2020. https://doi.org/10.25424/CMCC/ANALISI_DEL_RISCHIO
2. European Commission. COM/2021/550 final - 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality; 2021.
3. https://mimit.gov.it/images/stories/documenti/it_final_necp_main_en.pdf
4. Sperati S, Alessandrini S, D'Amico F, et al. A new Wind Atlas to support the expansion of the Italian wind power fleet. Wind Energy. 2024; 27(3): 298-316. doi:10.1002/we.2890.
5. Skamarock, W., Klemp, J., Dudhia, J. A description of the Advanced Research WRF Version 3. Tech. Note NCAR/;475;2008.
6. Delle Monache, L., Eckel, F.A., Rife, D.L., Nagarajan, B., Searight, K. Probabilistic weather prediction with an analog ensemble. Mon Weather Rev. 2013;141(10):3498-3516. doi:10.1175/mwr-d-12-00281.1
7. Lacavalla, M., Bonanno, R., Sperati, S. Dataset MERIDA per il calcolo dei tempi di ritorno delle principali minacce meteorologiche per l'alimentazione dei modelli di vulnerabilità della rete. Ricerca di Sistema (RdS); Milano; 2020.
8. Jimenez, P.A., Dudhia, J. Improving the representation of resolved and unresolved topographic effects on surface wind in the WRF model. Journal of Applied Meteorology and Climatology, vol. 51, n. 2, pp. 300-316, 2012.