Towards a future-proof climate database for European energy system studies

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Towards a future-proof climate database for European energy system studies

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Abstract

In 2013, the European Network of Transmission System Operators (TSOs) for electricity (ENTSO-E) created the Pan-European Climate Database (PECD), a tool that has underpinned most studies conducted by TSOs ever since. So far, the different versions of the PECD have used so-called modern-era 'reanalysis' products that represent a gridded amalgamation of historical conditions from observations. However, scientific evidence suggests, and recent European regulation requires, that power system adequacy studies should take climate change into account when estimating the future potential of variable renewable resources, such as wind, solar and hydro, and the impact of temperature on electricity demand. This paper explains the need for future climate data in energy systems studies and provides high-level recommendations for building a future-proof reference climate dataset for TSOs, not just in Europe, but also globally.

1. Introduction

The Earth's climate is changing due to sustained emissions of anthropogenic greenhouse gases (GHGs) (IPCC 2021). Each successive report published by the Intergovernmental Panel on Climate Change has highlighted the need for accelerated decarbonization of energy systems, which are responsible for approximately two-thirds of global GHG emissions (IEA 2021, IPCC 2021). Plans to tackle this issue and aim for economy-wide carbon neutrality in the coming decades have recently been put forward by many countries. The recent European Green Deal (European Commission 2019) highlights the expected efforts required to transform Europe to carbon-neutrality by 2050. The 'Fit for 55' package (European Commission 2020) targets a 55% reduction in EU's net emissions by 2030 compared to 1990. It puts variable renewable energy sources (RESs), such as wind and solar photovoltaics, at the forefront of the fight against climate change. In response to the recent conflict in Ukraine, the European Commission presented the REPowerEU Plan, that proposes to increase the 'Fit for 55' 2030 target for renewables from 40% to a 45% target.

The continuous integration of RES in electricity systems creates challenges for all actors in the sector, including Transmission System Operators (TSOs). Many of these challenges stem from the variable nature of the underlying resource, i.e. wind speed or solar irradiation (Craig *et al* 2018, Yalew *et al* 2020), compounded by the effects of a changing and variable climate (Wohland *et al* 2017, Tobin *et al* 2018, Pryor *et al* 2020, Gernaat *et al* 2021, Bloomfield *et al* 2021).

Climate change also effects the severity and frequency of extreme events impacting on energy system assets (Schaeffer *et al* 2012, Novacheck *et al* 2021, EPRI 2022), patterns of electricity demand (Auffhammer *et al* 2017, van Ruijven *et al* 2019, Bloomfield *et al* 2021) and thermal generation (Petkov *et al* 2016, Miara *et al* 2017). Therefore, leveraging climate-related information that can represent both historical and future conditions of power system operation with sufficient accuracy is essential for TSOs, policymakers and other stakeholders as they plan the electricity grid for a future carbon-neutral energy system (Bloomfield *et al* 2021, Craig *et al* 2022).

The use of climate databases for energy systems analysis has picked up its pace over the last few years with the advent of reanalysis data. These databases are based on the underlying climate parameters from reanalysis data (e.g. wind speed, solar radiation, and temperature), from which the energy-related parameters required for energy system modeling (e.g. capacity factors for solar photovoltaic (PV) and wind farms), are derived. Reanalysis datasets represent a gridded amalgamation of historical conditions from observation stations. Most studies investigating various facets of RES-dominated energy systems, across Europe (Grams *et al* 2017, Brown *et al* 2018, Zappa *et al* 2019, IEA 2021), the United States (Jenkins *et al* 2021, Novacheck *et al* 2021) and Africa (Lee and Callaway 2018) have leveraged comprehensive reanalysis datasets in their associated modeling and analysis. While these allow for the analysis of energy systems within the covered historical period (e.g. on the impact of weather patterns on day-to-day operation of RES assets), they do not enable such analysis under future climate conditions. Though several recent power system studies have considered the impact of climate change (van Zuijlen *et al* 2019, Harang *et al* 2020), the representation of climate change was simplified and limited.

In the current Pan-European Climate Database (PECD), impact of climate change is fairly limited. A trend correction was applied to temperature data to consider historical climate change in version 3.1, but no projected future impacts were considered (Troccoli and Almond 2021). Yet, this dataset is used to assess the long-term energy supply and demand trends, policy ambitions and technological developments, notably in the European Resource Adequacy Assessments[8]. To provide a robust assessment of current and future energy systems under climate change, it should consider data from climate projections (Craig *et al* 2022, Mays *et al* 2022). An update of the PECD is thus required.

The rest of this paper is structured as follows. Section 2 presents the type of studies that use climate databases and the requirements that they impose; section 3 provides a list of recommendations to consider climate change and section 4 concludes with the solution chosen by European Network of Transmission System Operators (TSOs) for electricity (ENTSO-E) for the upcoming version 4.0 release of the PECD.

2. Target studies and their needs

In the European context, TSOs perform several types of studies at both national and regional levels, requiring high-quality climate datasets[9]:

(Regional) Adequacy studies, aimed at assessing the security of electricity supply for consumers;

- Cost-benefit analysis studies, aimed at identifying capacity expansion needs and where additional investments in cross-border transmission capacity could deliver the most benefits for European consumers and producers;
- Operational security analyses, which assess the extent to which the grid can transport electricity from producers to consumers, even in the case of unplanned outages in network elements;
- Market design studies, which are used to evaluate if reforms to the European electricity market design could improve market functioning.

The adequacy studies are the most demanding in terms of the granularity of the climate data required. These studies evaluate resource adequacy risks in the short- to the mid-term horizon (up to ten years ahead). Examples of these studies include (a) national resource adequacy assessments performed by TSOs or other national authorities (ELIA 2019, 2021, RTE 2021, TenneT 2021, Terna 2021), (b) regional adequacy studies, such as those conducted within the Pentalateral Energy Forum (Penta SG2)[10] or (c) continental studies, such as the European Resource Adequacy Assessment (ENTSO-E 2019, 2021). These studies aim to assess whether the expected supply-side (e.g. power plants and/or storage) and demand-side (e.g. demand-side response) resources available in the system are sufficient to meet the expected electricity demand over the considered time horizon.

To quantify the impact of climate variability, which introduces both supply- and demand-side uncertainties, such studies usually consider multiple weather years. Currently, to get a relevant long-term view of the adequacy situation, Monte Carlo

[8] www.acer.europa.eu/electricity/security-of-supply/european-resource-adequacy-assessment.

[9] While these are given for the European context, similar types of studies are conducted around the world either by TSOs, national policymakers, and regulators.

[10] The PENTA countries include Austria, Belgium, France, Germany, Luxembourg, the Netherlands, and Switzerland.

scenarios are built by sampling weather years and forced outage pattern associated with the thermal units. Traditionally, when enough scenarios are run, the adequacy of the system is evaluated via metrics such as energy not served and loss of load expectation.

Adequacy studies should consider extreme weather events that drive the design of the system, and studies have shown that climate change could increase both the frequency and severity of such events (IPCC 2021). Therefore, robust datasets that represent both the historical and future expected climate conditions are of growing importance for system adequacy studies even when considering only thermal resources. These become absolutely crucial within an energy transition that will likely entail a higher dependence on weather-dependent RES for electricity supply, in particular for studies looking several decades ahead.

The current release of the PECD (version 3.1) contains 35 historical climate years based on the ERA5 reanalysis (Hersbach *et al* 2020). While this dataset provides a reasonable description of the current climate and its year-to-year variations, its limited temporal coverage creates challenges for capturing the extreme events that strongly shape the design of RES-dominated power systems, nor is the spatial resolution sufficient to capture mesoscale processes or complex topography. Furthermore, considering the growing evidence of changes in climate due to anthropogenic activities (Craig *et al* 2018, Cronin *et al* 2018, Yalew *et al* 2020), the current release is not the most appropriate to accurately represent what the climate and its variability will be in the next few decades.

With a high penetration of RES for electric supply, if adequacy studies are to remain useful, they must also evaluate the full range of weather-driven supply outcomes, while at the same time considering the impact of weather on demand. Therefore, it is necessary to keep the physical, spatial, and temporal correlations between the different climate variables once transformed into power consumption and generation (Craig *et al* 2022) especially as compounding effects can lead to more extreme events (Zscheischler *et al* 2018, van der Wiel *et al* 2019). More details on the consideration in the representation of climate are listed in the supplementary material.

3. Recommendation towards a climate database incorporating the effects of climate change

Considering the observed and foreseen evolution of the climate, EU policies, and the available data from the climate community, several recommendations can be made to consider climate change in long-term energy systems studies.

1. **Climate projections should be included in the reference datasets for energy studies**
   Current energy systems and future investments will operate under changing climate conditions. Energy assets have a technical lifetime ranging from 20 years for wind turbines and solar panels to more than 50 years for hydropower plants, nuclear power plants, and certain transmission infrastructure. Complementarity between the different kinds of studies (see section 2) should be improved when designing future energy systems. For example, asset investments and systems' operation studies should coherently and clearly define their assumptions regarding climate, starting from common well-defined and documented climate datasets. Furthermore, wherever possible, they should engage with climate science expertise to ensure that the climate data being used is interpreted appropriately. Defining a full taxonomy of how climate parameters interact with and propagate through energy system assets is an important aspect. It is outside the scope of the present paper but has been covered by several publications (see for instance Troccoli *et al* 2014, Troccoli 2018, Craig *et al* 2022, WMO 2022a, 2022b)
2. **Assessing long-term climate change may require different approaches to near-future climate**
   For relatively short temporal horizons (e.g. one to ten years) the 'forced response' to increasing atmospheric GHG concentrations is likely to be modest compared to the magnitude of pre-existing natural year-to-year variations in many geographic regions (including Europe). Thus, historical data, such as reanalysis, are likely to provide a reasonable baseline estimate for the range of near-future climate conditions which may be faced, provided that the temporal coverage is long enough and appropriate detrending strategies are applied (particularly for near-surface temperature). Still, methodological issues persist, as multivariate detrending methods are challenging to handle and the patterns of meteorological situations, particularly of extremes, might be different under a changing climate. If trend correction is not considered, then the historical data may not accurately represent near-future conditions.

   Over longer time horizons more attention is required. Past trends can be difficult to estimate (e.g. for extreme events or compound hazards) and the complexity of the climate system means that the potential for some level of circulation change cannot be ignored. Thus, while there is no singular 'perfect' (or even 'best') method to produce detailed climate data representing the distant future, the use of data incorporated appropriately from climate-model output seems essential. Where such data is used, however, it must be carefully benchmarked against historic datasets.

3. **Flexible climate-to-energy modeling solutions need to be developed**
The power sector is evolving at a quick pace. Changing regulations, new targets, and fast-evolving technologies make it necessary to develop flexible modeling tools that can be easily adapted with minimal user effort. This applies especially to energy conversion models that, coupled with technical specifications, transform the climate information into demand and generation data. Therefore, significant improvements are needed in the way energy conversion models are designed and provided. These should offer the user a standard version, based on transparent methodology and open-access code, and the possibility to easily modify the code for improvements or specific needs. These conversion models should be, at least partially, based on physical models that explicitly specify the physics of the climate-to-energy conversion process.
4. **Balance is needed between scientific accuracy and operational constraints**
Not all users and applications have the same capabilities to account for multiple climate projections. Therefore, the use of climate projections will be challenging for some applications, and different options must be proposed to account for various constraints, needs and resources. The development of new climate projection-based datasets needs to come together with clear methodological recommendations for those applications that cannot run multiple scenarios in a Monte Carlo-like set-up. The provision of climate projections and the corresponding energy information must be accompanied by clear guidance and related tools to select the most relevant sub-ensemble of data from the entire dataset, depending on the technical constraints and the expected target of each study.
5. **Co-design, user training and ongoing dialog are crucial components for assessing climate risk in energy systems**
The use of any climate dataset requires careful consideration in the handling of the data within. Climate projection datasets are more complex than reanalysis data and will bring about a significant shift for users. However, the change can be managed with proper training and communication. It must be seen as a long-term investment towards more robust approaches that will be easier to update in the future when new projections become available. In line with the climate services' development over the recent years, a co-design approach must be used to develop the new datasets (Goodess *et al* 2019).
6. **Databases of climate and energy parameters should be open source as far as possible**
Providing open access to the climate and energy parameter database allows other stakeholders from industry, academia, and the broader energy community to work together, spot errors, and ultimately improve the datasets and tools.

4. Conclusions and implementation into the PECD v4.0

Climate is changing on average and through changes in the amplitude, frequency, and impact of extreme events. Therefore, climate information from past decades is becoming less relevant for long-term planning of future energy systems. EU targets for decarbonization require standard inputs and transparent assumptions about the considered scenarios, including climate and the conversion to energy variables. Thus, climate data and standardized energy conversion models should come from recognized, open access, authoritative sources.

Based on the recommendations listed above, the choice has been made by ENTSO-E to extend the reanalysis-based PECD with future projections derived from climate models in the next release. This will allow historical variability to continue to be better quantified while at the same time providing a means to estimate the impact of climate change on future conditions.

The new database, including climate data and related energy data, will be implemented by the European Centre for Medium-Range Weather Forecasts under the Copernicus Climate Change Service for the energy sector. This will provide various stakeholders with open-access to a common reference and state-of-the-art database. In addition, the availability of open and standardized energy conversion models will allow the running of studies based on the same assumptions. Furthermore, it will enable a large community to contribute to further developing the models, which will benefit the whole sector.

Data availability statement

No new data were created or analyzed in this study.

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