APPENDIX ON CLIMATE YEARS

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When performing Unit Commitment & Economic Dispatch over several Monte Carlo years (see dedicated Appendix on the subject), it is required to account for the climate impact. First because, when talking about renawables energy sources (RES), the weather variables will impact the final generated energy (with the so-called ‘capacity factors’). Secondly, the weather will also impact the final electricity consumption (the colder, the higher the consumption).

This is why, a climate database has to be used for the construction of thermo-dependent input data, namely the consumption (load) and RES generation (wind, solar and hydro) profiles. In this section, the forward looking climate database used by Elia since 2021 is described in more detail.

It is important to note that the content of the climate database is not developed by Elia, but by external climate experts. The aim of this section is to explain to the reader in a didactic way the content and process followed to construct such a database, but it does not aim to give all the nuances or assumptions taken to perform such process.

1. CONTEXT

In line with best practices used for European adequacy studies, Elia has, until 2021, always used the full PECD (Pan European Climate Database) from ENTSO-E. This consists of a set of more than 30 historic climate years (e.g. from 1982 to 2015, was used in the Adequacy and Flexibility study published in 2019). This database was updated once a year at the request of ENTSO-E. The same database was also used for the different MAF and PLEF studies, such as the MAF2020 [ENT-1], which was published at the end of 2020 and the PLEF GAA 2020 report, which was published at the beginning of 2020. Currently the ENTSOE PECD (PECD3.0) consists of a set based on the historical years from 1982 to 2019.

The ERAA methodology adopted in 2nd October 2020 (ACER decision 24/2020) requires that the future PECD reflects the evolution of climatic conditions as depicted in BOX 1 (copy of Article 4 (f) of the ERAA methodology). Elia anticipated this methodological evolution as from 2021 in order to already account for the impact of this target requirement included in the ERAA methodology.

In order to do so, Elia used the climate database developed by the French weather and climate service, Météo-France, which is also used by the French TSO (RTE) for its national adequacy assessments. Following the public consultation of Adequacy & Flexibility study published in 2021, Elia provided information about the methodology from Météo-France to market parties to facilitate their understanding of it. Those documents are available for download on Elia’s website [MET-1]. This section includes some further information about the methodology based on those documents, with the aim to give the reader an overview of the applied climate dataset.

ENTSO-E has also indicated in its implementation roadmap, that final targeted approach would indeed also include the use of a best forecast of future climate projection (the first option i) described in the ERAA methodology. For ERAA2021 and ERAA2022 however, ENTSOE still relies on option ii) ’weight climate years to reflect their likelihood of occurrence (taking future climate projection into account)’ by detrending the historical reanalysis-based PECD. This intermediate option allows to use historical variability while at the same time provides a first step towards estimating the impact of climate change on future conditions.

A new database PECD 4.0 including climate data and related energy data, will be implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) under the Copernicus Climate Change Service (C3S) for ENTSOE. The PECD 4.0 release from C3S to ENTSOE is expected earliest mid 2023, hence too late for usage in the Adequacy & Flexibility study to be published in June 2023 by Elia.

BOX 1: ERAA methodology on PECD

The ERAA methodology indicates that the future Pan European Climate Database should reflect the evolution of climatic conditions as depicted below (copy of Article 4 (f)).

> *(f) The expected frequency and magnitude of future climate conditions shall be taken into account in the PECD, also reflecting the foreseen evolution of the climate conditions under climate change. To this effect, the central reference scenarios shall either*
>
> *i. rely on a best forecast of future climate projection;*
> *ii. weight climate years to reflect their likelihood of occurrence (taking future climate projection into account); or*
> *iii. rely at most on the 30 most recent historical climatic years included in the PECD*
>
> *Other scenarios and sensitivities may rely on climate data beyond the one used for the central reference scenarios, e.g. pursuant to Article 3.6(e).*

2. METHODOLOGY TO CONSTRUCT 200 CLIMATE YEARS UNDER CONSTANT CLIMATE

A climate database includes time series of climate parameters (temperature, wind, etc.) for several geographical locations and for a certain period of time.

What can be found in the climate database of Météo-France?

Météo-France's database has the following characteristics.

- It takes into consideration more than 80 meteorological parameters such as:
  - temperature, relative humidity and air density at 2m;
  - zonal and meridian wind, strength and direction, at 10m and 100m;
  - cloudiness, global, direct and diffuse solar radiation;
  - precipitation (rain and snow).
- The meteorological parameters are available for more than 37000 location points uniformly distributed across Europe based on a 0.2° grid resolution in latitude and longitude (+/- every 20 km). Temperature time series are also available for more than 2000 European cities.
- The time series for each parameter and for each location point is provided on an hourly time step for 200 simulated climate years under a constant climate (see BOX 2).

The climate years used in this study are no longer historical climate years but are synthetic (simulated) climate years under a constant climate, with two main differences:

- the goal of synthetic representative climate years is to look further than today and to take a certain evolution of the climate into account;
- the goal of synthetic representative climate years under a "constant climate" is to obtain series of climate data which can be considered as equiprobable for a certain climate.

The meteorological parameters of this climate database are temporally consistent. They describe realistic, albeit fictitious, meteorological situations. The aim of such database is not to predict the exact weather for a given year but to provide a reliable set of data that can be used for probabilistic calculations such as resource adequacy assessments.

BOX 2: REPRESENTATIVE SYNTHETIC CLIMATE YEARS UNDER CONSTANT CLIMATE

Figure 1 illustrates the differences between climate database approaches. The key advantage of the climate years under constant climate of Météo-France is that it gives 200 potential realisations for the same target date, while accounting for the climatic evolution between past years and the concerned target date.

If one takes the example for the year 2000, the observed and realised historical measures will give the measured data of the year 2000. For the synthetic climate years with an evolving climate, there is also only one (synthetic) year 2000. However, for the synthetic climate years with a constant climate of the year 2000, 200 climate years are generated which are all plausible realisations that could have taken place over that year, as illustrated in Figure 1. Figure 1

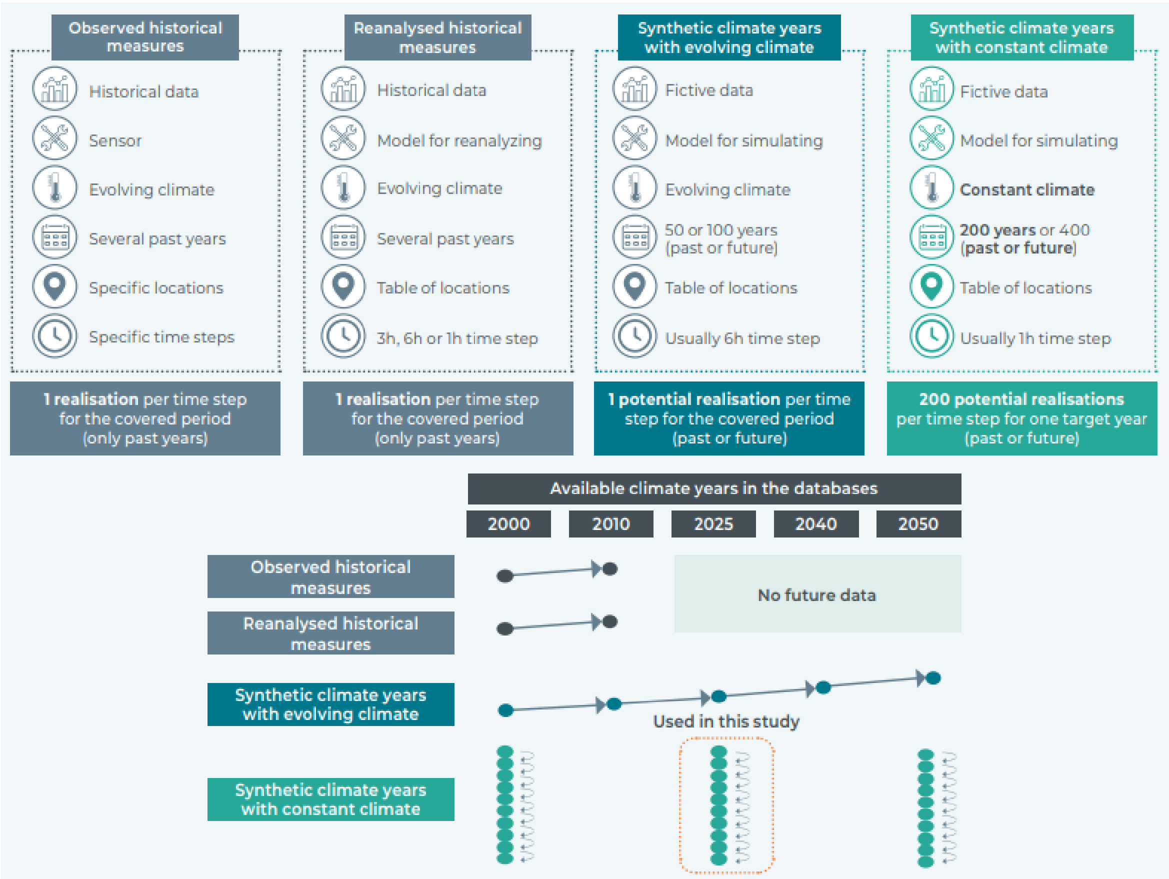

Figure 1 Comparison of climate database

In times of climate change, simulated climate years are a relevant tool for modelling the future climate. Furthermore, when it comes to studying the reoccurrence of rare events or events that have never occurred but could occur, it is better to use a constant climate which includes an interesting range of extreme events which have an equiprobable rate of occurrence [MET-1].

However, the synthetic climate years with constant climate only focus on one specific target year. Therefore, there is (for example) no data for the year 2001, while the three other databases would have data for the year 2001. This is not a problem, since the climate in 2001 is supposed to have been similar to the climate in 2000. Indeed, the climate years of a target year are deemed representative for a few years around that target year [MET-1].

As shown in Figure 1, Météo-France has generated synthetic climate years for three target years:

- 2000;
- 2025;
- 2050.

In the Adequacy & Flexibility study published in 2021, the climate years under the constant climate of 2025 are used for the 10-year period of this adequacy study, namely from 2022 to 2032, as it is the one that best represents the covered period.

Météo-France has been developing their own climate model (ARPEGE-Climat) since 1990 [MET-2]. A climate model aims to generate simulations of long periods based on the state of the atmosphere and its evolution.

As the climate depends to a large extent on the concentration of Greenhouse Gases (GHG), the climate model uses as input the GHG concentration for a target year, together with the temperature of the surface of the sea, as shown in Figure 2.

A real starting situation is given to the model which then calculates the meteorological values according to the physical equations of the atmosphere and its exchanges with the earth's surface. The equations for the evolution of the state of the atmosphere included in the model reflect the physical and thermodynamic laws. The model ran until it obtains 200 synthetic (but equiprobable) years. The meteorological values over Europe were archived at hourly time steps.

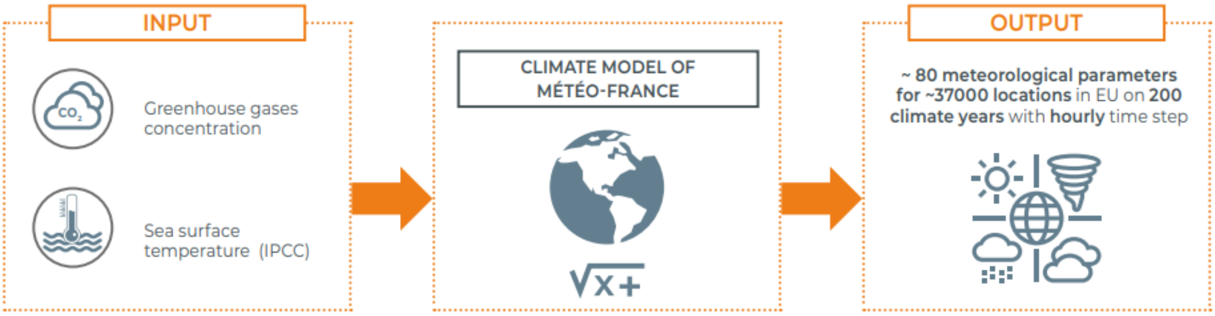

Figure 2 Input and output of the climate model of Météo-France

In order to obtain the climate years under the constant climate of 2025, Météo-France processed the data in three steps (see Figure 3):

- A first processing was executed for the target year 2000 as it enables comparing the obtained meteorological parameters with historical ones. A calibration was applied to mitigate the biases of the model and to ensure that the simulated climate years were statistically coherent with the historical ones;
- In a second step, climate years were generated for the target year 2050, with GHG concentration based on future possible evolutions (RCP pathways). The climate years for 2050 as output of the climate model contain the same kind of biases as the climate years for 2000. Therefore, a similar calibration was done. As two possible evolutions for 2050 were considered by Météo-France (RCP 4.5 and RCP 8.5), this step was performed twice;
- Finally, the climate years under the constant climate of 2025 were derived with an interpolation based on the climate simulations of 2000 and 2050 RCP 8.5.

More information on these three steps is given in the last section of this appendix.

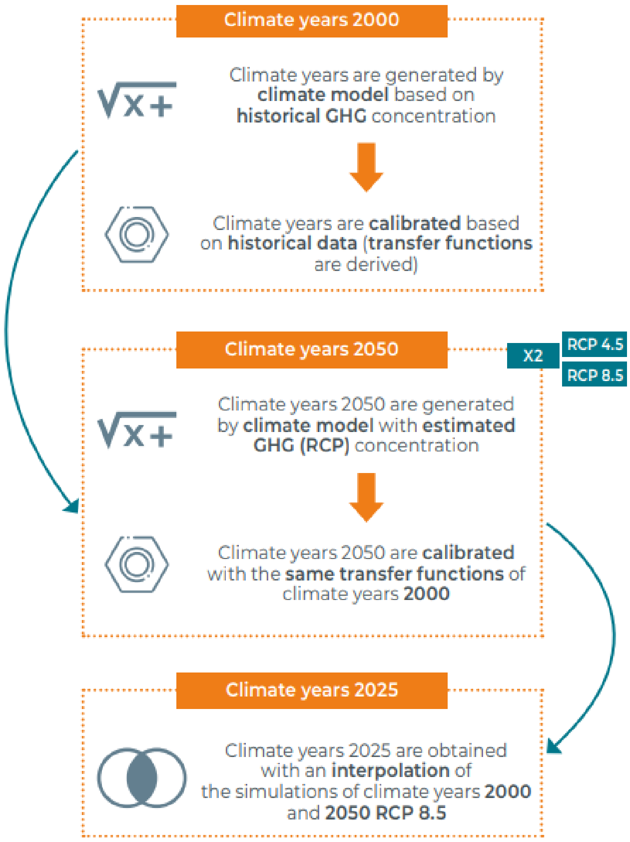

Figure 3 From climate years under constant climate of 2000 to climate years under constant climate of 2025

3. DISTRIBUTION OF COLD WAVES

Cold waves can have an important impact on adequacy requirements. Therefore it is valuable to look at these consecutive days of low temperature in the new synthetic climate years of 2025 compared to the historical climate years used up to now in ENTSO-E's and Elia's adequacy studies. Figure 4 shows the distribution of cold waves in Belgium in the two climate year databases. The cold waves are categorised based on their average temperature and their duration. The large majority (>80%) of the cold waves have an average temperature above -3°C in both databases. Regarding long cold waves, their occurrence is significantly reduced in the synthetic 200 climate years of 2025 compared to the historical climate years.

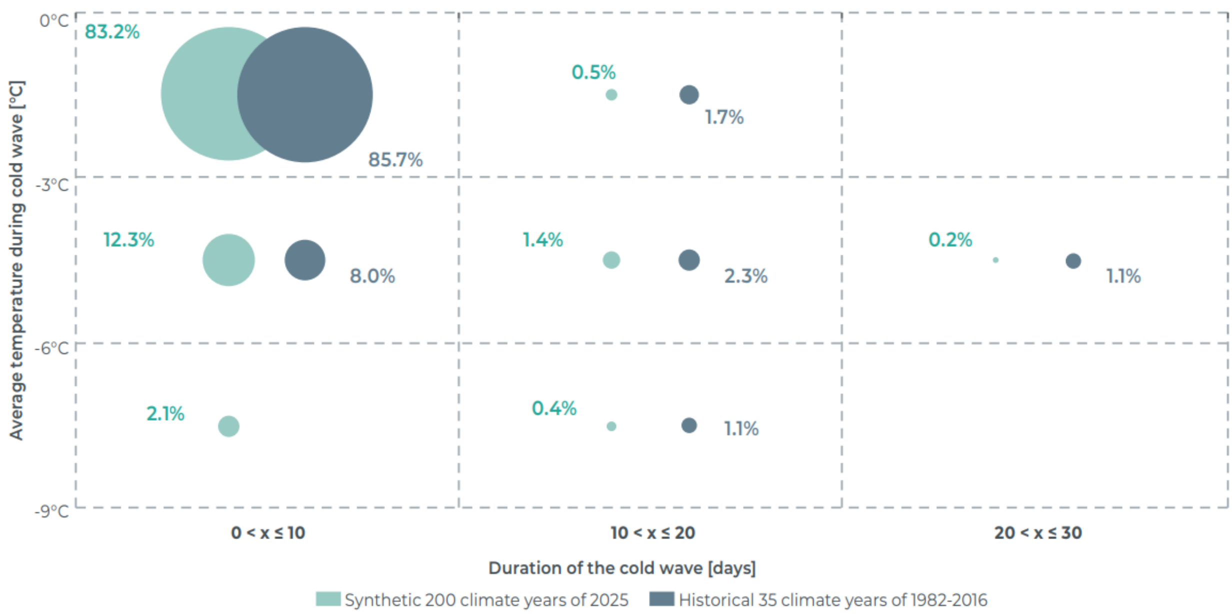

Figure 4 Comparison of distribution of cold waves in Belgium

4. FROM WEATHER VARIABLES TO GENERATION VARIABLES

To be used in a study, the meteorological data from the new climate database of Météo-France needs to undergo two main transformations:

- the values of thousands of points in Europe must be aggregated at country level (as modelled in this study);
- the wind and solar radiation need to be translated into electrical generation variables (e.g. from wind speed to wind turbine generation factors).

As the French TSO RTE also uses the climate database from Météo-France, they had already carried out the transformations of the weather variables. Therefore, Elia opted to reuse their aggregated and translated values.

The process to translate meteorological data into electricity generation factors is explained in Figure 5. It is first necessary to determine the **transfer functions** to apply (or also called 'infeed model'). To do so, RTE compared historical meteorological data with historical load factors and determined transfer functions based on a **statistical learning process** as explained in [RTE-1]. This was carried out per area and per technology. Once the transfer functions had been defined, they were updated to take technological evolutions into account and then applied on the new meteorological data from the 200 climate years under the constant climate of 2025, in order to finally get the time series of the new electricity generation factors.

These hourly electricity generation factors were then used to calculate the effective electricity produced based on the installed capacities of wind and solar generation, as explained in appendix dedicated to Unit Commitment & Economic Dispatch.

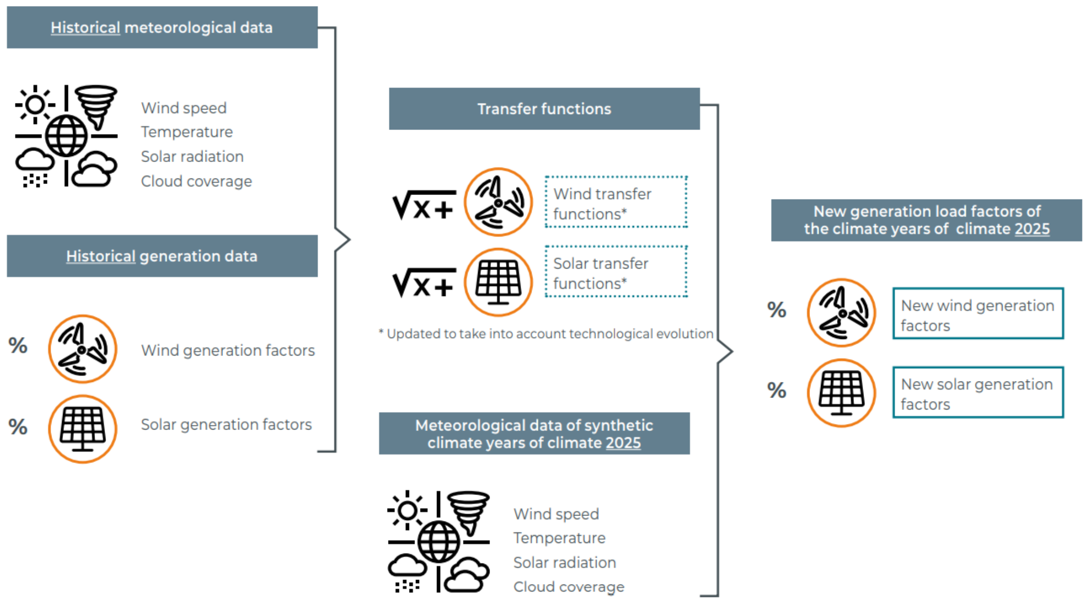

Figure 5 From weather variables to electricity generation factors

BOX 3: Correlation of climatic conditions

The various meteorological conditions that have an impact on renewable generation and electricity consumption are not independent of each other. Wind, solar radiation, temperature and precipitation are correlated for a given region. In general, high-pressure areas are characterised by clear skies and small amounts of wind, while low-pressure areas have cloud cover and more wind or rain.

Given the very wide range of meteorological conditions that countries in Europe can experience, it is difficult to find clear trends between meteorological variables for a given country. Figure 6 attempts to show the non-explicit correlation between wind production, solar generation and temperature for Belgium. The graph presents the seven-day average for these three variables for Belgium based on the 200 synthetic climate years of 2025 of Météo-France, but similar conclusions can be drawn on historical databases. The hourly or daily trends are not visible because the variables were averaged across each week; however, various seasonal and high-level trends can be observed, as outlined below.

- The higher the temperature, the lower the level of wind energy production. During winter there is more wind than in summer.
- The higher the temperature, the higher the level of PV generation. This is logical given that more solar generation can be expected during summer and inter-season months.
- When the level of wind energy production is very high, the level of PV generation tends to fall.
- During extremely cold periods, wind energy production falls while there is a slight increase in PV generation. This is a key finding that will affect adequacy during very cold weather conditions.

The meteorological data is also geographically correlated, as European countries are close enough to each other to be affected by the same meteorological effects. A typical example of this is the occurrence of a tense situation due to a cold spell which first spreads over western France, then over Belgium and followed by Germany. It is essential to maintain this geographical correlation between countries in terms of climate variables.

Given the high amount of renewable energy from variable sources that is installed each year in Europe and the fact that the electricity demand in some countries is highly sensitive to temperature, it is essential to maintain the various geographically correlated and time-correlated weather conditions in the study.

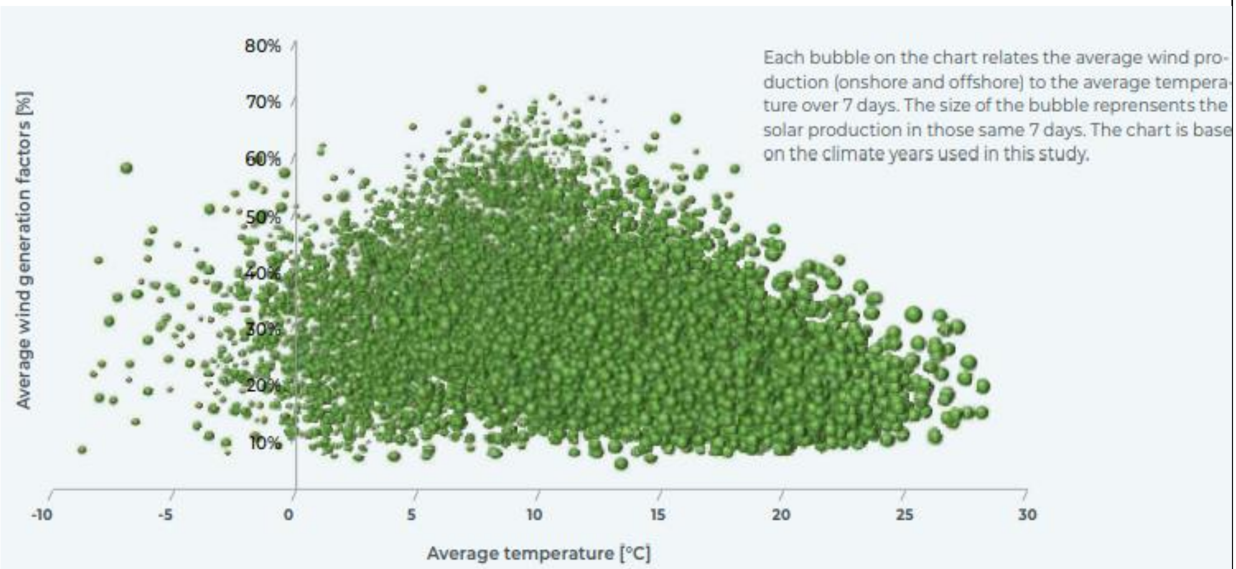

Figure 6 — Correlation between wind production, solar production and temperature (7-day average)

5. ADDITIONAL INFORMATION ON THE METHODOLOGY

This section aims at giving extra information on the following points

- Why and how is a calibration done?
- How are the GHG concentration estimated for 2050?
- Why and how is the interpolation done for the year 2025?

Why and how is a calibration done?

The calibration aims at correcting the biases that are inherent in any model. To do so, the 200 simulated climate years are compared with historical values around the year 2000 and transformations are applied to ensure the simulated climate years have the same statistical characteristics as the reference historical database. In this case, the reference used by Météo-France is the historical database HIRLAM/ERA-Interim at a resolution of 0.2° in latitude and longitude over the period 1984-2013 (centered around the year 2000).

After calibration, the median of the simulated values is matching the median of the historical values and that the simulated-200-years maximum and minimum values are well respectively above and below and the historical-30-years reference period. Therefore, the two databases have now similar statistical characteristics.

The transformations applied on the simulated climate years of the climate 2000 are called "transfer functions" that depend on the location point, date of the year and the hour of the day. As the simulated 2050-CY contains similar biases, the same transfer functions are applied.

How are the GHG concentration estimated for 2050?

In order to estimate the GHG concentration in the future, the scientists from the Intergovernmental Panel on Climate Change (IPCC – GIEC) have defined several hypothesis leading to different trajectories called Representative Concentration Pathway (RCP) [IPC-1]. Four different trajectories have been defined for climate change modelling. Each scenario represents a different radiative forcing value (2.6, 4.5, 6.0 and 8.5) leading to a possible future, depending on the GHG emissions in the next years. The RCP 8.5 scenario is the one leading to the highest increase in temperature.

Météo-France is simulating two RCP scenarios for the climate of 2050, the RCP 4.5 and RCP 8.5. The most pessimistic scenario for 2050, the RCP 8.5 is the one used in terms of temperature for the interpolation to 2025 (see after).

Why and how is the interpolation done for the year 2025?

As explained and shown by Météo-France in [MET-3], the interpolation to an intermediate climate between 2000 and 2050 allows a representation of the climate for the target year (2025) to be approached with good plausibility without having to implement a simulation specific to that target year.

The interpolation done by Météo-France for the 2025-climate is based on the simulations of 2000-climate and the 2050-RCP8.5-climate. Indeed, the actual evolution of the GHG concentration seems to follow the RCP 8.5 [MET-2], which leads to a higher increase in temperature.

The 200 simulated CY under the constant climate of 2000 are adapted for the 2025 constant climate by an interpolation of the statistical distribution of the 2000-CY and 2050-RCP8.5-CY.

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