G. ADEQUACY STUDY

Adequacy is the characteristic of a power system to be able to meet demand with supply. This characteristic is dependent on a great number of variables which are uncertain (e.g. renewable energy production varies from one year to another). Hence, accurately estimating a power system level of adequacy requires a probabilistic assessment. For this, 'Monte Carlo' simulations are often referred in the literature as the 'state-of-the-art' practice to assess adequacy of power systems. 'Monte Carlo' years, allow to define a wide range of future possible states.

This appendix will cover how these 'Monte Carlo' years are defined to run simulations, as well as how the outputs of these simulations are analysed to define the so-called GAP (i.e. the additional capacity needed to satisfy the adequacy criterion).

The methodology described here for calculating the needed capacity or margin on the system follows the ERAA methodology and builds on Elia's expertise gained over the past decade.

G.1. METHODOLOGY OVERVIEW

Assessing the needed capacity or margin for a given scenario requires three steps. The steps are run iteratively until a compliant solution is found.

1. The **first step is the definition of future possible states (or 'Monte Carlo years')** covering the uncertainty of the generation fleet (technical failures) and weather conditions (impacting RES generation and demand profiles due to thermo-sensitivity effects). For this, simulations should span as many as possible future states, called 'Monte Carlo' simulations (as described in Section 2).
2. The **second step** is the identification of **structural shortage periods**, i.e. moments during which the electricity production on the market is not sufficient to satisfy the electricity demand. **Hourly market simulations** are performed to quantify deficit hours for the entire future state. More information is available in Section 3.
3. The **third step** is to assess the **additional capacity needed (100% available)** to satisfy the legal adequacy criterion. This capacity is evaluated with an iterative process, as defined in Section 4.

G.2. 'MONTE CARLO' SIMULATION

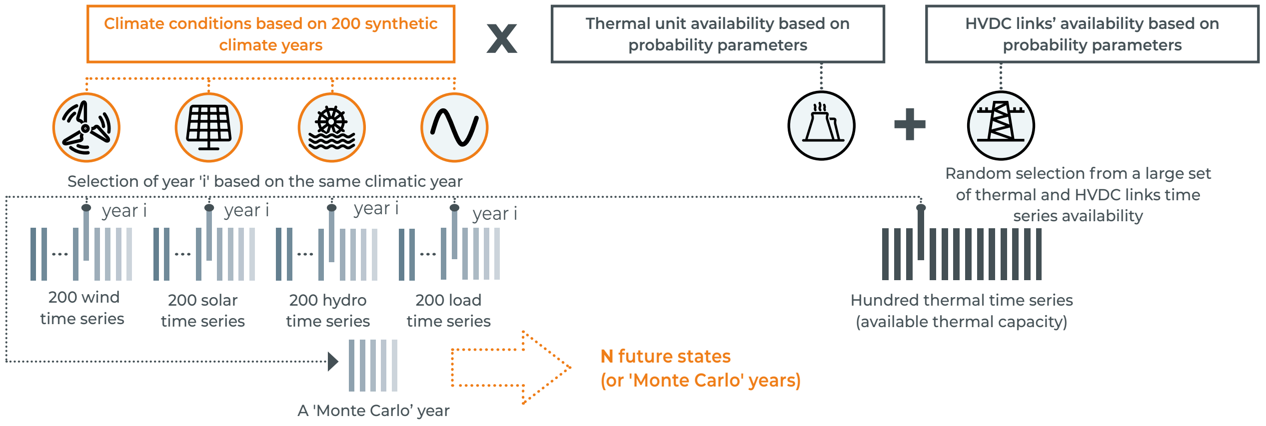
The first step consists of defining the different future states that will be simulated. Each future state (or 'Monte Carlo' year) is a combination of the following:

- **Climate conditions** for temperature, wind speed, solar irradiation and precipitation. This data is used to create time series of renewable energy generation and of consumption by taking into account the 'thermosensitivity' effect (see Appendix J for details over the climate database used for this study). The correlation between climate variables is retained both **geographically as well as temporally**. For this reason, the climatic data relating to a given variable (wind speed, solar irradiation, hydroelectric production inflows and precipitation or temperature) for a specific year is always combined with the data from the same climatic year for all other variables. This approach is applied to all countries in the studied perimeter.
- Random samples of **power plant and HVDC link** (not linking areas within the Core region) **availability are drawn by the model** by considering the parameters of outage rate and length of unavailability. As a result, various time series for the availability of the thermal facilities for each area and the availability of each HVDC link under consideration are found. This availability differs within each future state. Random outages are drawn following a 'Markov chain' approach, where the parameters used are the forced outage rate and the force outage duration length.

Each time series of the power plant availabilities is further combined with a given 'climate year' (i.e. wind production, solar production, hydroelectric production and electricity consumption) to constitute a 'Monte Carlo year' or 'future state'. Such an approach is fully compliant with the ERAA methodology. Figure G-1 illustrates this process.

For target years (horizons) where there is known information on future planned maintenance of units, the planned maintenance in the simulation is fixed according to this information. For the other units and for target years where such information is not available, planned outages are drawn by the model based on the parameters provided by the different TSOs and/or based on ENTSO-E's common data (publicly available). Note that for Belgium, no planned maintenance is assumed during winter months, unless the information was publicly available or was communicated at the time of the public consultation carried out on the scenarios and data.

FIGURE G-1 — GENERATION OF A ‘MONTE CARLO’ YEAR.



Each climatic year is chosen a number of times, each time in combination with a different random draw of power plant and HVDC links availabilities (i.e., a randomly chosen time series of the power plant availabilities). Each future state year is assumed to carry the same weight in the assessment as the climate database is constructed to have equiprobable years. The LOLE and EENS criteria are therefore calculated on the full set of simulated future states (or ‘Monte Carlo years’).

A probabilistic risk analysis requires the construction of a large number of future states, in order to ensure statistical representativeness and robustness. Each of these states can then be analysed and the results are used to determine the relevant adequacy indicators.

G.2.1. VARIABLES CONSIDERED FOR THE ‘MONTE CARLO’ SET-UP

A first set of key variables consists in climatic variables. The main characteristic of these variables is the mutual correlation between them on a time and geographical basis. In the framework of this study, the following climatic variables are considered:

- Hourly time series for wind energy generation (onshore and offshore);
- Hourly time series for solar energy generation (PV and CSP);
- Daily time series for temperature (used to calculate the hourly time series for electricity consumption);
- Hydro inflows;
- The correlation between those different climatic variables is further explain in Appendix J on climate years.

Another set of key variables are not correlated with the climatic variables, namely:

- parameters relating to the availability of thermal generation facilities on the basis of which samples can be taken regarding power plants’ unavailability;
- parameters relating to the availability of HVDC links (excluding those within Core as for those their unavailability is part of the flow-based domain calculation) on the basis of which samples can be taken regarding their availability;
- Other variables (see below) might have a potential impact on security of supply but given their nature are disregarded from the variables of the ‘Monte Carlo’ simulation. However, some events listed below are still taken into consideration in this study, by means of additional unavailability of units.

The ‘Monte Carlo’ simulations performed in this study disregard, the following events (this list is not meant to be exhaustive):

- long-term power plant unavailability (sabotage, political decisions, strikes, maintenance due to additional inspections, bankruptcy, terrorist attacks, wars, etc.). Those events can be assessed separately by additional unavailability of units (on top of the ones drawn by the ‘Monte Carlo’ simulation);
- interruption of the fuel supply or cooling of the power plants (low water levels, heatwave...);
- extreme cold freezing water courses used for plant cooling;
- natural disasters (tornadoes, floods, etc.).

G.2.2. AMOUNT OF ‘MONTE CARLO’ YEARS (CONVERGENCE)

As stipulated in the ERAA methodology in Article 4, paragraph 2 I, a convergence check needs to be performed. In order to perform the check, the coefficient of variation is defined with the following equation as set in the ERAA methodology:

$$\alpha_N = \frac{\sqrt{Var[EENS_N]}}{[EENS_N]}$$

where EENS is the expectation estimate of ENS over N number of ‘Monte Carlo’ samples,

$$\text{i.e. } EENS = \frac{\sum_{i=1}^{N} ENS_i}{N},$$

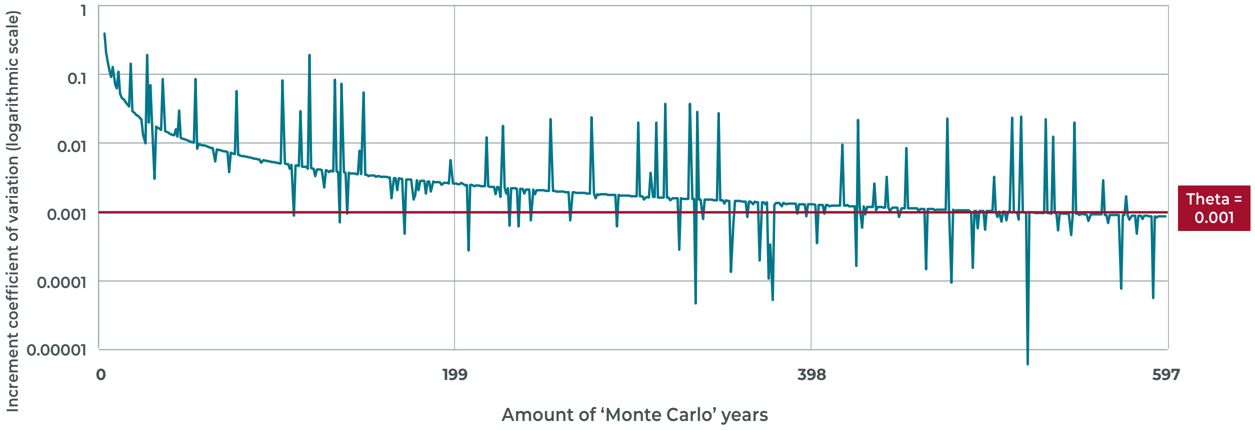
i = {1, ..., N} and $Var[EENS]$ is the variance of the expectation estimate, i.e. $Var[EENS_N] = \frac{Var[EENS]}{N}$.

For this study, the EENS of Belgium is monitored and used for the convergence check. In order to define the amount of ‘Monte Carlo’ years (N) that needed to be simulated, the increment coefficient of variation (α) is assessed and compared to a chosen threshold (Θ)

$$\frac{\alpha_N - \alpha_{N-1}}{\alpha_{N-1}} \leq \Theta$$

The threshold chosen for this study equals Θ = 0.001. An illustration of the convergence for a given simulation is provided in Figure G-2.

FIGURE G-2 — EXAMPLE OF CONVERGENCE ASSESSMENT ON THE ENS DEPENDING ON THE AMOUNT OF ‘MONTE CARLO’ YEARS SIMULATED BASED ON THE CHOSEN THRESHOLD.



Convergence is typically reached after simulating around 600 ‘Monte Carlo’ years within adequacy simulations (three times the full climate database of 200 climate years combined with different draws of thermal and HVDC availabilities). The 200 calendar climate years lead to 199 years from September to August.

When determining the adequacy margin or need, this same amount of ‘Monte Carlo’ years is simulated at each iteration. These simulations are thus rather computationally intensive. To give an indication of the complexity, the optimisation process of each simulation consists of a matrix integrating around 420,000 variables and 160,000 constraints.

To remain within computationally reasonable times, several constraints of the unit commitment not affecting adequacy results are relaxed. In addition, adequacy simulations are run from September to the end of the winter period, as this period concentrates all the hours with energy not served in Belgium. This allows the problem and computational time to be optimised and kept within reasonable limits, since simulations typically need to be performed iteratively a large amount of times (e.g. when looking for either the needed capacity or the adequacy margin).

A smaller amount of ‘Monte Carlo’ years is simulated for the economic simulations and economic viability assessment (EVA), as those require full year simulations with all economic constraints activated.

The following amount of ‘Monte Carlo’ years are taken into account:

- 597 ‘Monte Carlo’ years for adequacy results in the main scenarios of the study. In some iterations, only focusing on the winter period;
- 398 ‘Monte Carlo’ years for adequacy results related to sensitivities to the main scenarios of the study;
- 199 ‘Monte Carlo’ years for the economic viability assessment and clustering for some iterations (see below);
- Clustering of 199 ‘Monte Carlo’ years for economic results.

For some of the aspects, an additional clustering of those years is performed. The clustering allows the amount of years to be reduced to a smaller number, while keeping the same weights of the analysed parameters. Such an approach is for instance used for some intermediate iterations performed in the Economic Viability Assessment (EVA) or for the flexibility means assessment. To avoid any loss of accuracy, a full set of ‘Monte Carlo’ years is re-simulated after a given number of iterations (k) within the intermediate iterations considered and the clusters are then recreated based on the outcomes of these full simulations. Finally, to ensure that the results are robust, the EVA iterative approach is concluded with a full ‘Monte Carlo’ year simulation (see Appendix K for further details).

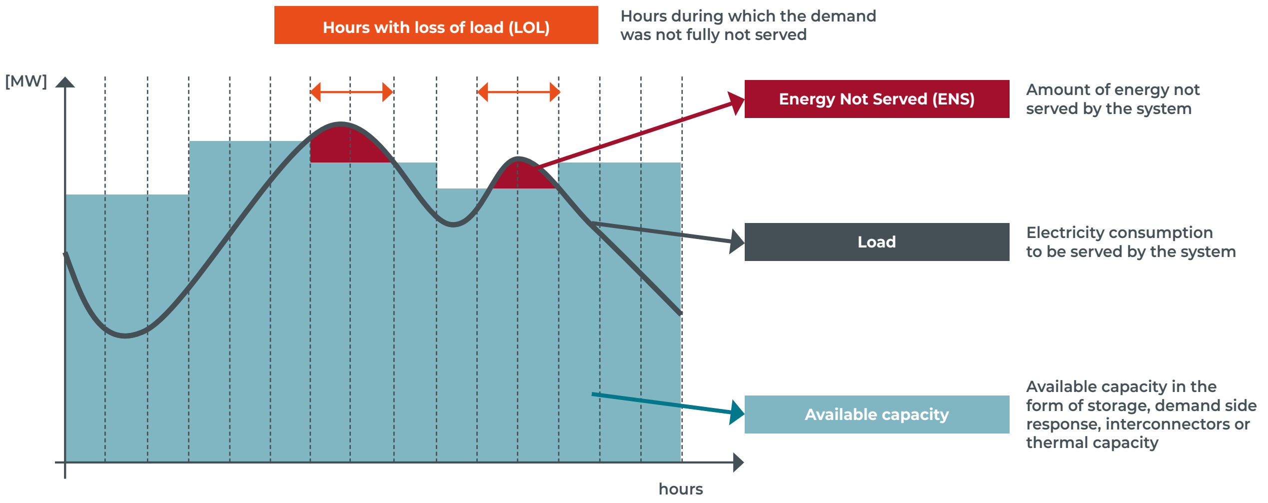
G.3. STRUCTURAL SHORTAGE PERIODS

The second step of each iteration run involves identifying periods of structural shortage, i.e. times when the available generation capacity (including storage and demand side response) and imports are not sufficient for meeting demand. To this end, the European electricity market is probabilistically simulated on an hour-by-hour basis, followed by an assessment of the output.

The simulation is performed with the Antares Simulator software. The optimised dispatch simulation identifies periods of structural shortage, i.e. times when available capacities on the supply side (including the contribution from imports) are insufficient to meet the demand. If, for a given hour, the combination of generation capacity, storage, imports and demand side response is short (by 1 MW or more) compared to the capacity required to meet demand, this corresponds to one hour of structural shortage (loss of load hour (LOL)), or an 'energy not served' (ENS) situation.

The Figure G-3 illustrates how the loss of load hours and the hours with ENS are quantified for one 'Monte Carlo' year.

FIGURE G-3 — LOL AND ENS QUANTIFICATION WITHIN HOURLY SIMULATIONS OF A GIVEN 'MONTE CARLO' YEAR.



Once the LOL and ENS are quantified for each 'Monte Carlo' year, it is possible to calculate the following indicators:

- **LOLE:** Average Loss of Load hours over the whole set of simulated 'Monte Carlo' years;
- **EENS:** Average Energy Not Served per year over the whole set of simulated 'Monte Carlo' years.

These indicators are calculated based on the available market capacity as defined in the scenarios and following the ERAA methodology.

If there are 'out-of-market' capacities such as strategic reserves contracted by the country or bidding zone, these can further decrease the LOLE and EENS after the market, but only for that given country or bidding zone.

G.4. REQUIRED ADDITIONAL CAPACITY OR MARGIN

Once the moments of structural shortage are identified for each 'Monte Carlo year' , their distribution (quantified in hours) can be established and thus the LOLE and EENS indicators can be calculated. On this basis, the adequacy indicators of the electrical system are evaluated and compared to the legal adequacy criteria (reliability standard) of the different countries.

If the adequacy criteria is not satisfied, **additional generation capacity** (in steps of 100 MW), **which is considered 100% available is added** to the concerned market area. The adequacy level of the new system obtained is again evaluated (by repeating again step 1 'definition of future states' and step 2 'identification of structural shortage periods with verification of the adequacy criteria'). This operation is repeated several times, adding a fixed capacity of 100 MW (100% available) each time, as long as the legal criteria are not satisfied. On the other hand, if the simulation without any additional generation capacity complies with adequacy criteria, **the margin on the system is examined** through a similar approach.

The block size of 100 MW Is chosen to be as small as possible, while still ensuring statistically robust results for the determination of the volume. Especially when searching for the tail of the distribution (e.g. LOLE criterion), this statistical robustness is a limiting factor. Choosing a smaller step size might have led to a calculation result that differed depending on the random seeding of the model [ELI-1]. The 100 MW block size is also the resolution used in the scope of the evaluation of strategic reserve volume and the other adequacy analyses performed by other TSOs and within ENTSO-E. It is important to note that in the framework of the CRM calibration report, the same block size of 100 MW is used to calibrate the model to reach the reliability standard in Belgium. However the CRM calibration parameters resulting from the simulation are expressed to the nearest MW. Figure G-4 illustrates the process followed.

FIGURE G-4 — ITERATIVE PROCESS FOR THE VOLUME CALCULATIONS