APPENDIX ON ADEQUACY STUDY

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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 used in the literature as Monte Carlo years helps 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 output of these simulations are analysed to define the GAP (i.e. : the additional capacity needed to satisfy adequacy criteria).

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.

1. Methodology overview

Looking for the needed capacity or margin for a given scenario is performed in 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 many possible future states. For this, Monte-Carlo simulations are ran (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 criteria. This capacity is evaluated with an iterative process, as defined in Section 4.

A time series of the power plant availabilities is associated to a 'climate year' (i.e. wind, solar, hydroelectric and electricity consumption) to constitute a 'Monte Carlo year' or 'future state'. Such an approach is fully compliant with the ERAA methodology. Figure 1 illustrates this process.
For the horizons where there is known information on the future planned maintenance of units, the planned maintenance is fixed according to this information. For the other units and for the years where such information is not available, the planned outages are drawn by the model based on the parameters provided by the different TSOs or based on ENTSO-E common data (publicly available). Note that for Belgium, no planned maintenance is assumed during winter months, unless the information is publicly available or is communicated during the public consultation carried out on the scenarios and data.

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, sun 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 the appendix dedicated to Climate Years for details over climate database used for this study. The correlation between climate variables is retained both **geographically and time-wise**. For this reason, the climatic data relating to a given variable (wind, solar, hydroelectric or temperature) for a specific year is always combined with the data from the same climatic year for all other variables (see Appendix on climate years for more details). This approach is applied to all countries in the studied perimeter.
- Random samples of **power plant and HVDC link** (not within a meshed grid) **availability are drawn by the model** by considering the parameters of outage rate and length of unavailability. This resulted in various time series for the availability of the thermal facilities for each area and the availability of each HVDC link under consideration. This availability differed in each future state. Outages are drawn following a Markov chain, where the parameters are the forced outages and the event lengths.

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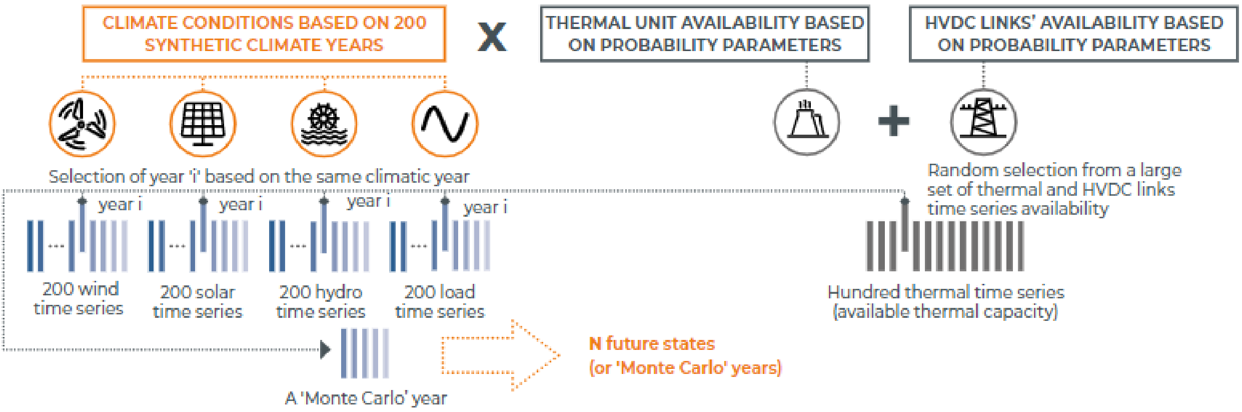

Figure 1 : generation of a 'Monte Carlo' year. The latter is constructed by combining a climate year (impacting climate related variable) and a time series describing availability of thermal power plants & HVDC links.

Each climatic year is simulated a number of times with the combination of random draws of power plant availability. 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.

A probabilistic risk analysis requires the construction of a large number of future states. Each of these states can then be analysed to determine the adequacy indicators.

Variables taken into account 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. 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 CHP);
- 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 the appendix 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 a meshed grid) 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 in from the variables of the 'Monte Carlo' simulation. However, some events listed below are 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, etc.). Those events are assessed separately by additional unavailability of units (on top of the one 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.).

Amount of Monte Carlo years (Convergence)

As stipulated in the ERAA methodology in Article 4, paragraph 2 (e), 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, 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 a below 0.001. An illustration of the convergence for a given simulation is provided in Figure 2.

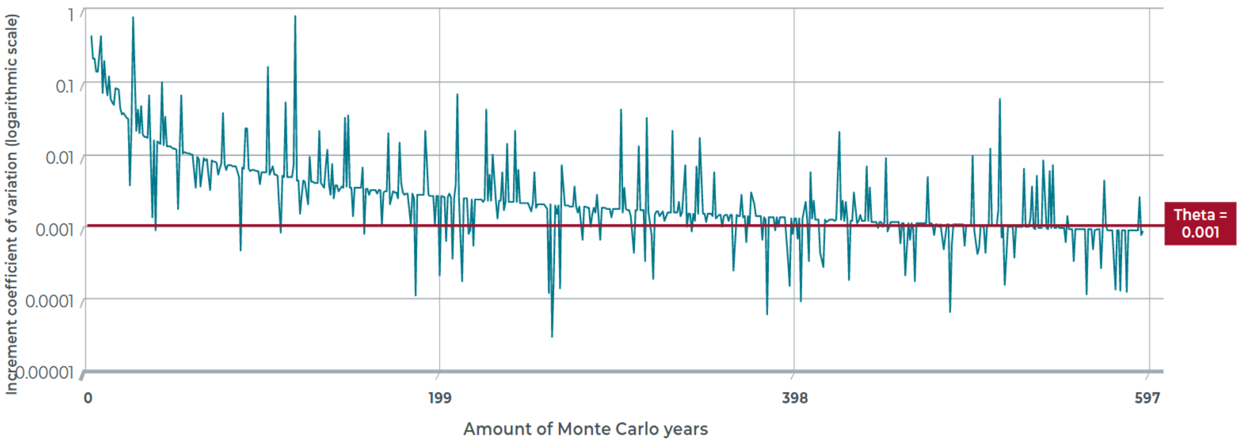

Figure 2 : Example of convergence assessment on the ENS depending on the amount of 'Monte Carlo' years simulated based on the chosen threshold.

Convergence is obtained in previous studies after simulating around 600 Monte Carlo years for adequacy simulations (three times the full climate database combined with different draws of thermal and HVDC availability). The amount will be reviewed in order to comply with the convergence check. When determining the adequacy margin or need, for each iteration this same amount of Monte Carlo years is simulated. These simulations are very computationally intensive. In order to give an indication of the complexity, the optimisation process of each simulation consists of a matrix integrating around 400,000 variables and 150,000 constraints.

In order 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. Indeed, these simulations 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). Indeed, those requires full year simulations with all economic constraints activated.

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 EVA or for the flexibility means assessment.

3. Structural shortage periods

The second part of each iteration step 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 ANTARES. The optimised dispatch simulation identified periods of structural shortage, i.e. times when available capacities on the supply side are insufficient for meeting 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 3 illustrates how the loss of load hours and the hours with ENS are quantified for one Monte Carlo year.

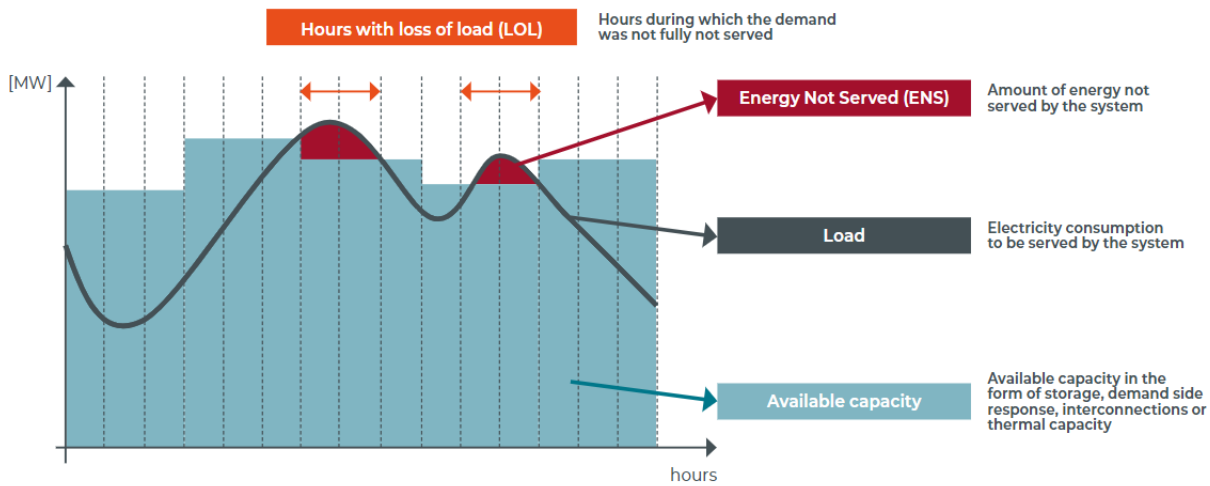

Figure 3 : 1 'Monte Carlo' year: LOLE & ENS quantification

Once the LOL and ENS are quantified for each 'Monte Carlo' year, one can calculate the following indicators:

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

These indicators are calculated based on the available market capacity as defined in the scenarios and following the methodology set in the ERAA.
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 for the given country or bidding zone only.

4. Additional capacity needed

Once the moments of structural shortage are identified for each 'Monte Carlo year' (LOLE and EENS indicators), their distribution (quantified in hours) is established. On this basis, the adequacy indicators of the electrical system are evaluated and compared to the legal adequacy criteria (reliability standard). 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 (definition of future states and 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. Figure 4 illustrates the process followed.

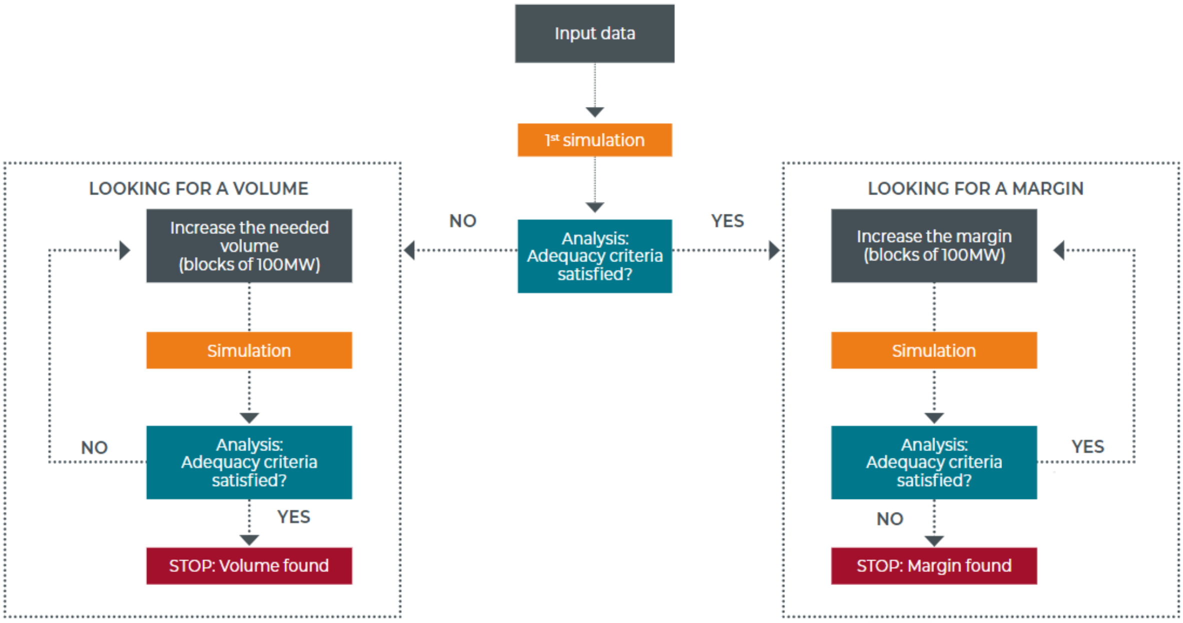

Figure 4 : iterative process for the volume calculations

References

[ELI-1] https://eliagroup.sharepoint.com/sites/UsersGroup/Documents/Forms/AllItems.aspx?ga=1&id=%2Fsites%2FUsersGroup%2FDocuments%2FElia%20Users%20Group%2FTF%20Implementation%20Strategic%20Reserve%2F2018%2F20180709%2F20180709_presentations_Elia_adequacy_study_2018_SR_design_EN%2Epdf&viewid=75b28522-1747-458f-a445-4621f2fd59bf&parent=%2Fsites%2FUsersGroup%2FDocuments%2FElia%20Users%20Group%2FTF%20Implementation%20Strategic%20Reserve%2F2018%2F20180709