Study on the outage parameters of generation units and DC links

28/10/2022

Submitted to the public consultation of Adequacy & Flexibility study 2024-34

1. Contents

1. Context

This note explains the methodology by Elia and N-Side for the determination of the necessary metrics regarding forced and planned outages to be used in the Adequacy & Flexibility study 2024-2034, the Low Carbon Tender for 2024-2025, and future adequacy studies performed by Elia. The outage metrics are used, on the one hand, in the modelling of generation units, pumped-storage and HVDC links and, on the other hand, the determination of derating factors for the Low Carbon Tender and future market-wide CRM scenarios. Planned and forced outages are often referred to as planned and unplanned unavailabilities respectively, in the rest of this document we will refer to planned and forced outages.

2. Outage rates in previous adequacy studies

The following table describes how Elia takes into account planned and forced outages of Belgian generation units in its models.

Planned outage	**Forced outage**
• If the maintenance dates are known in the transparency platforms of the producers in the framework of REMIT (for the first years analysed), those are explicitly taken into account; • If the maintenance dates are not known yet or beyond the scope of REMIT, then a maintenance rate (in-line with the ENTSO-E common data) is used. The maintenance is then drawn by the model ex-ante the simulation. • No maintenance is considered on individually modelled units for Belgium during winter months (November to March) unless provided in the transparency platform of the producers (or bilaterally).	3 parameters are calculated : • Forced outage rate $\text{Average FO rate} = \frac{(\text{FO energy } 2011 \rightarrow 2020)}{\text{FO energy } 2011 \rightarrow 2020 + \text{Available energy } 2011 \rightarrow 2020}$ • Average forced outage duration $\text{Average FO duration} = \frac{\text{Sum}(\text{FO duration}_{2011} + \ldots + \text{FO duration}_{2020})}{\#\text{FO over } 2011 \rightarrow 2020}$ • Average amount of events $\text{Average } \#FO = \text{Average}(\# FO_{2011} + \ldots + \#FO_{2020})$

In the framework of the last "Adequacy & Flexibility" study (Elia, 2021), the forced outage parameters were calculated on a yearly basis on a 10 year period for Belgian units. The used data was a combination of ENTSO-E transparency platform (ETP) where available and combined with and Elia's internal database where needed.

The method used to determine the outage indicators posed some limitations:

- No data is available in ETP (ENTSO-E Transparency Platform) data before 2015.
- No ETP data is available for units <100 MW.
- Elia's internal database only provides daily granularity.

- Some discrepancies between Elia's internal database and ETP were observed.
- There are only a limited amount of units in Belgium for some technologies for which data is available. This does not ensure statistically robust data:
  - Nuclear: 7 units
  - CCGT: 20 units
  - OCGT: 11 units
  - CHP: 27 units
  - TJ: 13 units
  - Pumped storage: 2 units
  - Biomass: 5 units
  - Incineration stations: 13 units
- Due to the limited dataset a specific year can have a strong impact on the unavailability indicators.

Given these limitations, the goal of this study is to provide a more correct and robust method for estimating the unavailability parameters.

3. Goal of the study

Given the limitations explained in the previous paragraph, there are number of objectives for this study. The main goal of the study is to obtain sound and robust outage indicators to be used in upcoming studies to be performed by Elia. This translates to a list of objectives set out for this study:

- Consolidate the dataset from ETP and Elia's internal database;
- Ensure data quality of the dataset;
- Validation of the indicators with other countries or other sources;
- Calculation of the required indicators;
- Perform additional analysis on the indicators;
- Provide updated indicators to be used in the framework of AdFlex 23;
- Ensure robust indicators to avoid doing updates every year.

The study is limited to DC links and generation units of the following technologies:

- Combined Cycle Gas Turbine (CCGT)
- Open Cycle Gas Turbine (OCGT)
- Combined Heat Power (CHP)
- Turbo Jets (TJ)
- Pumped Storage (PSP)

For nuclear units, Elia performed a detailed analysis of outages in the context of the CRM DY 2027-28 calibration in June 2022 and refers to this note (* taking only technical forced outages into account Appendix: Elements to determine for the availability of the Belgian nuclear units (done by Elia)).

4. Methodology

To achieve these objectives, outage indicators were calculated and used to compare different data sources and countries. The outage indicators were also used to do a literature review and to perform additional analysis. Finally, the required outage indicators necessary for the Adequacy & Flexibility study 2024-2034 were calculated.

4.1 Outage indicators

There are 3 relevant indicators regarding both planned and forced outages. These are the average rate, the average duration and the average number of events (see Figure 1). Given the way Elia models outages, forced outages are of particular interest in this study.

	Planned unavailability	Forced outage
Average rate	$\frac{1}{T}\cdot\sum_{t=1}^{T}\left(\frac{PO\ energy_t}{Total\ energy_t}\right)$	$\frac{1}{T}\cdot\sum_{t=1}^{T}\left(\frac{FO\ energy_t}{FO\ energy_t + Available\ energy_t}\right)$
Average duration	$\frac{1}{T}\cdot\sum_{t=1}^{T}\left(\frac{1}{PO_t}\sum_{i=1}^{PO_t} PO\ duration_i\right)$	$\frac{1}{T}\cdot\sum_{t=1}^{T}\left(\frac{1}{FO_t}\sum_{i=1}^{FO_t} FO\ duration_i\right)$
Average number of events	$\frac{1}{T}\cdot\sum_{t=1}^{T} PO_t$	$\frac{1}{T}\cdot\sum_{t=1}^{T} FO_t$

Where T is the number of years considered
Where PO_t, FO_t are the number of events for year t

Figure 1: Overview of indicators for planned and forced outages

The indicators from Figure 1 should be understand as:

- The forced outage rate is the ratio of unplanned unavailable energy to the available energy;
- The planned outage rate is the amount of planned availability to the total energy that could have been produced. The total energy that could have been produced is the unplanned unavailable energy + the planned unavailable energy + the available energy;
- Average duration of forced of planned outages;
- The average amount of outage per year.

4.2 Data source assessment

In this step, a list of possible data sources was gathered and each source was assessed in order to get the correct data from the best available source. As such, Elia's internal database, ENTSO-E Transparency Platform (ETP) and transparency platforms from producers active in the Belgian electricity market were assessed. Table 1 summarizes the advantages and disadvantages of the various assessed data sources.

	ETP	Elia DB	Transparency platforms
Description	ENTSO-E Transparency Platform (ETP)[1]	Elia's internal database	Producers transparency platforms such as NordPool[2], EDF[3], TotalEnergies[4], Engie Transparency[5]
Advantages	• Legal obligation for units larger than 100 MW to report outages • Large sample size: outage data for all ENTSO-E bidding zones • Reporting of partial outages • 15 minuts time granularity • Public information	• Outage data on all unit sizes • Data avalable for more than 10 historic years	• Reporting of partial outages • 15 minutes time granularity • Public information
Disadvantages	• No data for units <100 MW • Only data available as from 2015	• Only data for Belgium • Only daily granularity • No legal obligation to publish • Not public information	• Mainly data for units >100 MW • Different platforms per producer • Limited amount of years

Table 1: Overview of data sources assessment

Based on this assessment it was concluded that ETP will be used were possible and completed with Elia's internal data where no ETP data is available. Producers' transparency platforms were generally found to provide the same data as was available on ETP, only provide data for a limited years and create the complexity of combining numerous data sources. In addition, not all producers have a data platform and very little data can be found on smaller units.

4.3 Definition of the data sample

Only a limited number of units for each technology exists in Belgium and that for some technologies (e.g. CHP) most units are small and little ETP data is available. As such, for Belgium the data sources for each technology is presented on Table 2.

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1 **ENTSO-E Transparency Platform (entsoe.eu)**
2 **Nord Pool - REMIT UMM (nordpoolgroup.com)**
3 **List of Outages | EDF FR**
4 **Transparency | TotalEnergies**
5 **Publications - BE,FR,NL,DE.xlsx (live.com)**

	ETP	Elia DB
CCGT	20	0
OCGT	1	10
CHP	1	26
PSP	1	1
TJ	0	13

Table 2: Repartition of Belgian units between databases

In order to obtain a larger and more representative sample, the data for Belgium is combined with ETP data for a list of representative other countries for all technologies considered and the outage indicators are calculated on this combined dataset. The other countries considered in this study are:

- France;
- Netherlands;
- Germany;
- United Kingdom;
- Italy.

Since data in ETP is only available as from 2015, the outage metrics are calculated on the time horizon 2015-2021 for the whole dataset, for each data source and each country.

4.4 Data Quality and pre-processing

Both ETP and Elia's internal database were found to contain some data quality issues which were corrected by applying 3 pre-preprocessing steps:

1. Removing duplicate outages: some outages are reported twice for the same period and should therefore only be considered once.
2. Cleaning of overlapping outages: some outages were found to be overlapping with other outages. This would cause outages to be counted twice for some periods. Overlapping outages were therefore split and overlapping periods removed;
3. In case a forced outage is immediately followed by a planned outage, the planned outage is converted to a forced outage. It is assumed that an unexpected forced outage cannot change to a planned outage after a short period of being in forced outage. In the opposite case where a planned outage is followed by a forced outage, nothing is done.

4.5 Literature review

The forced outage rates calculated for Belgium and other representative countries were compared with results from other studies on outage rates and the outage rates given in by ENTSO-E in the common data for thermal units.

The sources considered in the literature review are:

- The annual system report by REE[6];
- 2021 State of the Market Report for PJM by Monitoring Analytics (MA)[7];
- 2021 State of Reliability by NERC[8];
- Electricity Capacity report by National Grid[9];
- Common data used in the ERAA & TYNDP studies by ENTSO-E.

Other sources were consulted as well but provided no clear distinction between reasons for unavailability.

4.6 Methodology overview

Following the analysis steps described in the previous paragraphs the approach to obtain the final outage indicators for the Adequacy & Flexibility study 2024-2034 is summarized on Figure 2.

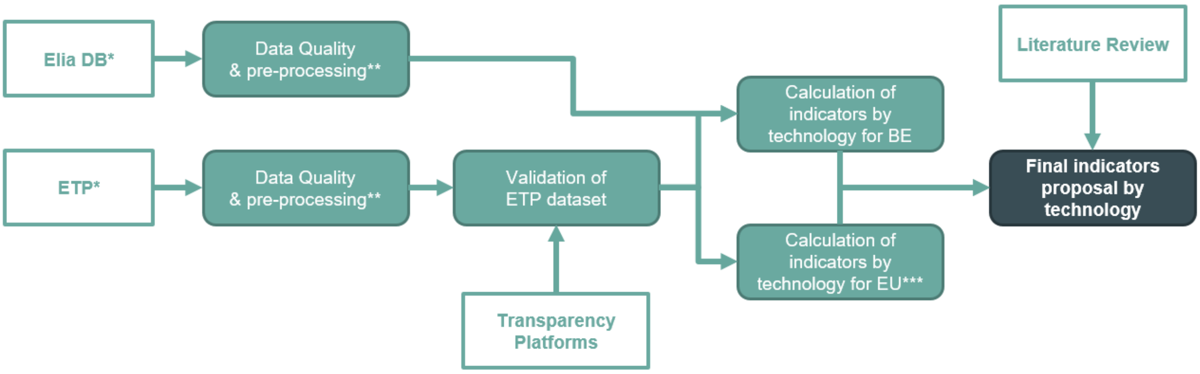

Figure 2: Methodology applied to calculate indicators by technology

First, the relevant data was collected from the relevant sources. After applying the pre-processing to improve the data quality, the data was compared to producers' transparency platforms. This robust dataset was then used to calculate the necessary indicators for the Belgium and other countries. After a comparison of the results with the results found in a literature review, the final list of outage indicators was created. The overview of resulting indicators to be used in the Adequacy & Flexibility study for 2024-2034 can be found in chapter 7 of this document.

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[6] https://www.ree.es/en/datos/publications/annual-system-report

[7] Monitoring Analytics - PJM State of the Market - 2021

[8] https://www.nerc.com/pa/RAPA/PA/Performance Analysis DL/NERC_SOR_2022.pdf

[9] National Grid ESO Electricity Capacity Report 2021: findings of the Panel of Technical Experts - GOV.UK (www.gov.uk)

5. Overview of the resulting forced outage rates for the Adequacy & Flexibility study 2024-2034 per technology

5.1 CCGT

As can be observed on Figure 3a, the calculated forced outage rate for CCGT decreases compared to the value last calculated by Elia in the framework of the CRM Y-4 auction for delivery year 2027-28 but is in line with the values given by ENTSO-E and within the range of forced outage rates put forward in other studies. The decrease compared to the CRM value is explained by high forced outage rates in the years 2012-2014 which were included for the CRM but are not considered in the new approach. Figure 3b shows that the distribution of forced outage rates for CCGT is stable across the considered years.

Figure 3: Forced outage rates for CCGT – Detailed analysis

The resulting value for the forced outage rate for CCGT to be used in the Adequacy & Flexibility study 2024-2034 is **5.5%**.

5.2 OCGT

As can be observed on Figure 4a, the forced outage rate for OCGT increases slightly compared to the value last calculated by Elia in the framework of the CRM Y-4 auction for delivery year 2027-28 but is in line with the values given by ENTSO-E and within the range of forced outage rates put forward in other studies. The increase compared to the CRM value is explained by high forced outage rates in observed in 2020 and 2021 as can be observed in Figure 4b.

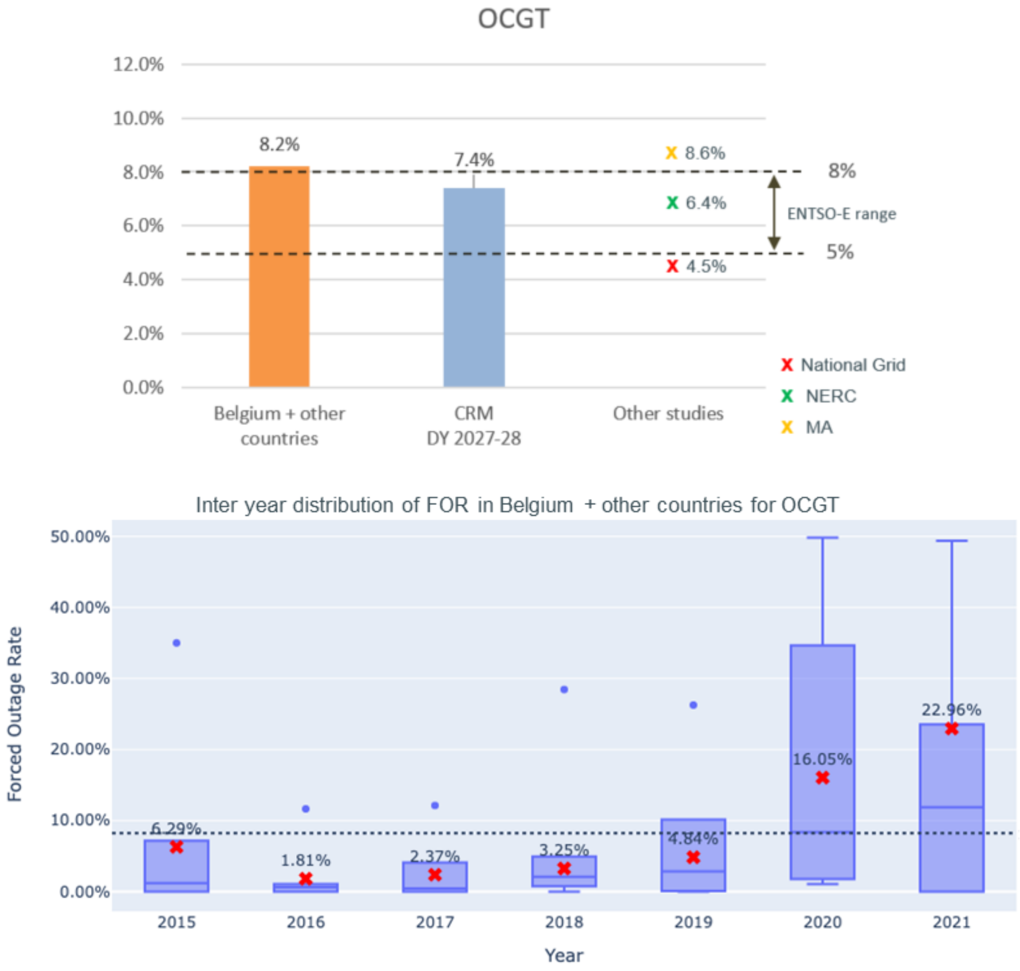


Figure 4: Forced outage rates for OCGT – Detailed analysis

The resulting value for the forced outage rate for OCGT to be used in the Adequacy & Flexibility study 2024-2034 is **8.2%**.

5.3 CHP

As can be observed on Figure 5a, the forced outage rate for CHP decreases slightly compared to the value last calculated by Elia in the framework of the CRM Y-4 auction for delivery year 2027-28 and is lower than the value calculated by ENTSO-E. The resulting value is within the range of forced outage rates put forward in other studies. The decrease compared to the CRM value is explained by high forced outage rates in observed in the 2012-2014 period which is not considered anymore in the new approach. There is only a limited amount data available for CHP on ETP. This limited sample size explains the high variation of forced outage years across yeas visible in Figure 5b.

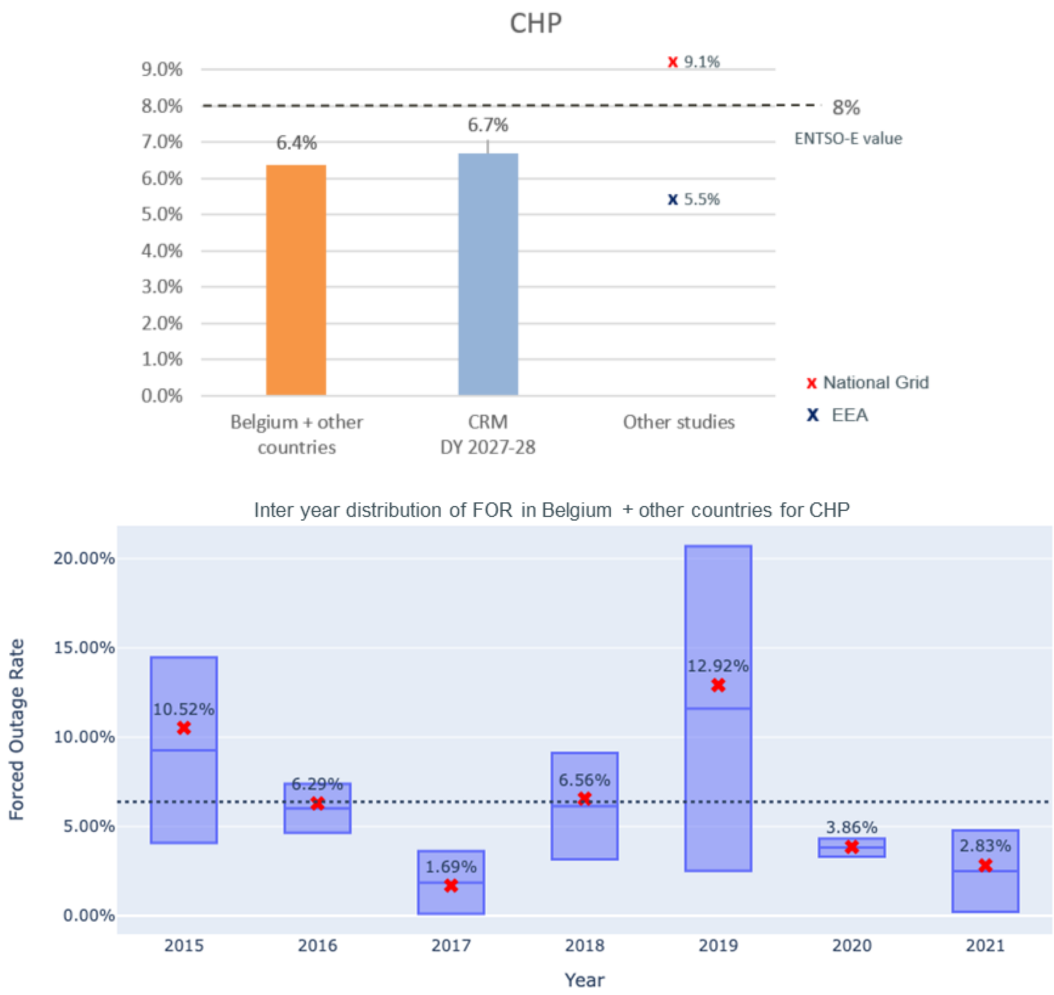
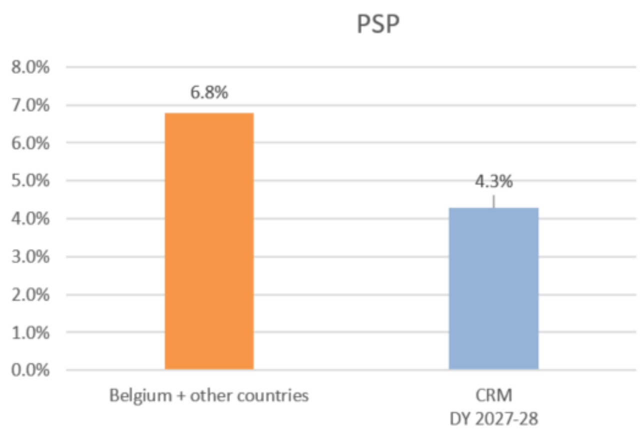


Figure 5: Forced outage rates for CHP – Detailed analysis

The resulting value for the forced outage rate for CHP to be used in the Adequacy & Flexibility study 2024-2034 is **6.4%**.

5.4 Pumped Storage (PSP)

As can be observed on Figure 6a, the forced outage rate for pumped storage increases compared to the value last calculated by Elia in the framework of the CRM Y-4 auction for delivery year 2027-28. No other sources were found for forced outage rates on PSP units and no value is given by ENTSO-E. The increase is explained by a high forced outage rate in 2021 as visible on Figure 6b and the inclusion of units from other countries



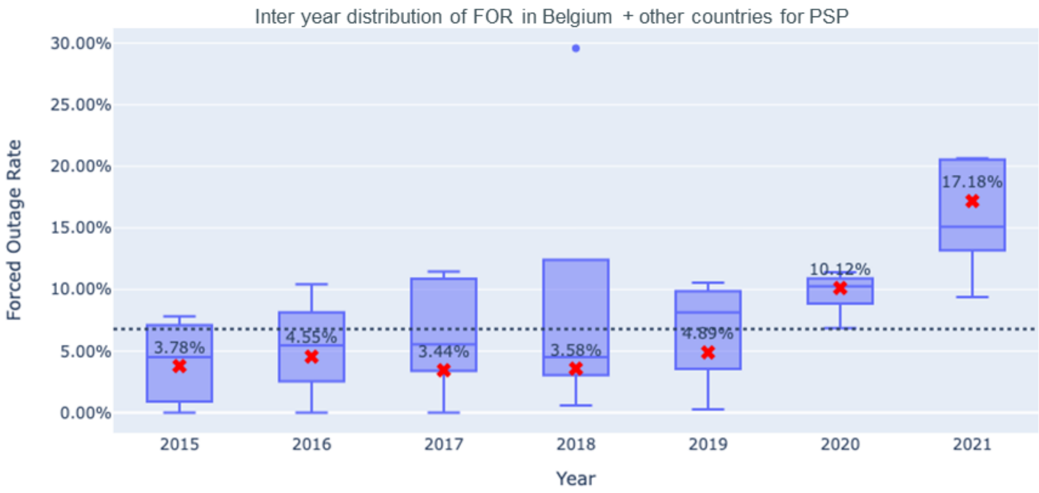


Figure 6: Forced outage rates for PSP – Detailed analysis

The resulting value for the forced outage rate for PSP to be used in the Adequacy & Flexibility study 2024-2034 is **6.8%**.

5.5 Turbojets (TJ)

As can be observed on Figure 7a, the forced outage rate for turbojets increases compared to the value last calculated by Elia in the framework of the CRM Y-4 auction for delivery year 2027-28 and falls within the range given by ENTSO-E for oil fired units. No other sources were found for forced outage rates on TJ units. The increase is explained by the inclusion of units from other countries and higher forced outage rates in recent years as can be observed in Figure 7b.

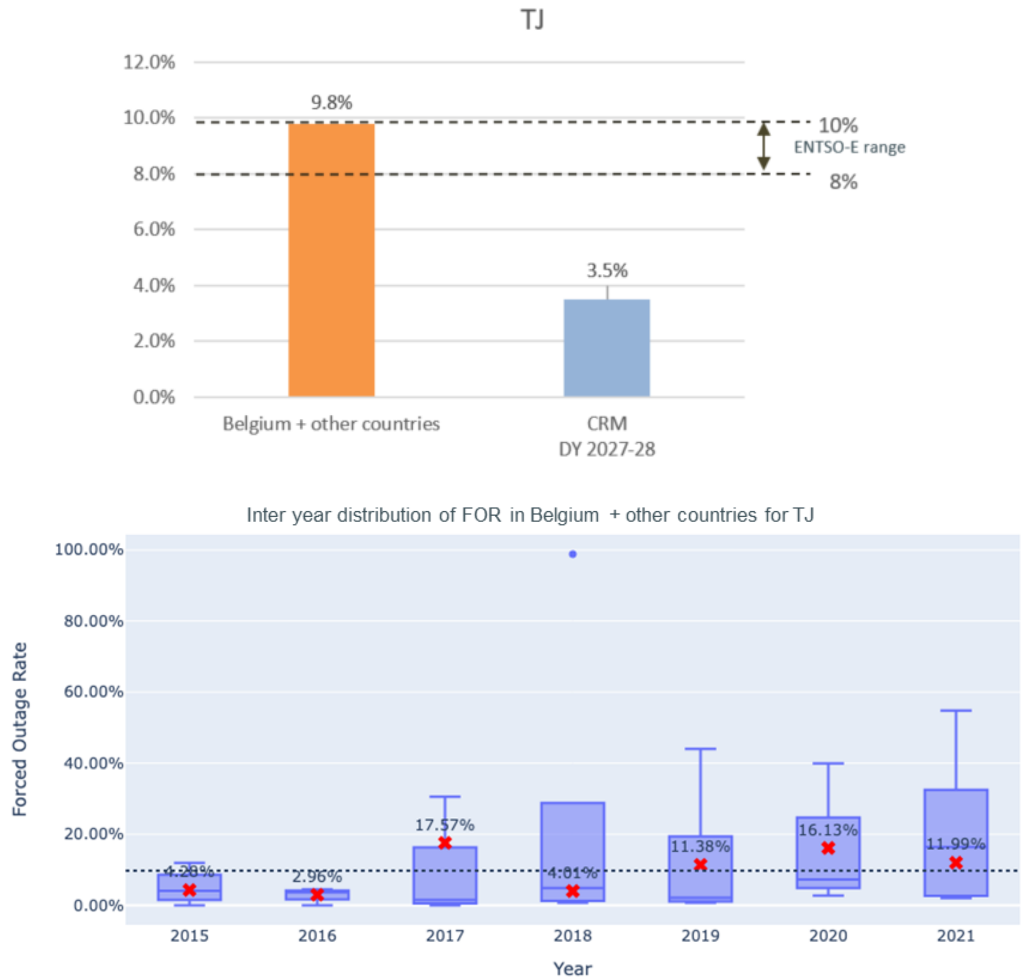


Figure 7: Forced outage rates for turbojets – Detailed analysis

The resulting value for the forced outage rate for TJ to be used in the Adequacy & Flexibility study 2024-2034 is **9.8%**.

5.6 DC links

The forced outage rate for DC links was obtained using a similar approach as for the thermal units (Figure 8). The ETP data for all North-Sea DC links was used for the 2015-2021 period. The resulting value is slightly higher than the value given in the common data of ENTSO-E but in line with a recent study, also by ENTSO-E, on the availability of HVDC links in the Nordic region[10]. The value shown for the ENTSO-E HVDC study is a combination of unplanned maintenances, disturbance outages and limitations.

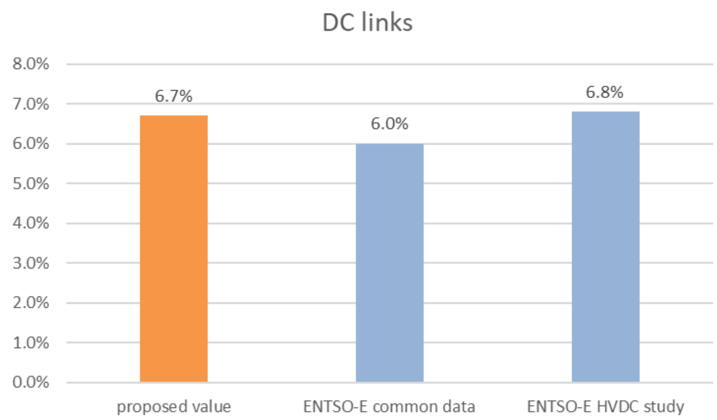


Figure 8: Forced outage rates for DC links – Detailed analysis

The resulting value for the forced outage rate for DC links to be used in the Adequacy & Flexibility study 2024-2034 is **6.7%**.

[10] 2021_ENTSO_E_HVDC_Utilisation_and_Unavailability_Statistics.pdf (azureedge.net)

5.7 Nuclear

Nuclear was not in scope of this study as Elia already performed an analysis for this in the framework of the CRM Y-4 auction for delivery year 2027-28. The calculation of the outage indicators for nuclear is the same as was published in the public consultation for the scenario of the CRM 2027-28 auction and is again added in the appendix of this document. Elia calculated 3 types of outages which could impact the availability of nuclear availability during the winter months.

- The **technical forced outage rate** related to short technical malfunctions:

$$technical\ FO\ rate = \frac{FO\ energy\ 2012 \rightarrow 2021}{FO\ energy\ 2012 \rightarrow 2021 + Available\ energy\ 2012 \rightarrow 2021} = \mathbf{4.0}\%$$

- The **long-lasting forced outage rate** related to exceptional events:

$$'Long\ lasting'\ FO\ rate = \frac{(FO\ days\ + EE\ days)2012 \rightarrow 2021}{(FO\ days + EE\ days + Available\ days)2012 \rightarrow 2021} - 'Technical'\ FO\ rate = \mathbf{16.5}\%$$

- The **winter planned outage rate** related planned outages during winter:

$$PO\ rate = \frac{PO\ days\ in\ winter\ 2012 \rightarrow 2021}{Total\ days\ in\ winter\ 2012 \rightarrow 2021} = \mathbf{8,1}\ \%$$

In line with the Ministerial Decree on the reference scenario for the CRM Y-4 auction for delivery year 2027-28 from the 9th of September 2022[11], Elia proposes to use the availability rate that can be considered as the sum of the technical and long-lasting forced outage rates.

$$FO\ rate =' Technical'\ FO\ rate +' long - lasting' FO\ rate = 4{,}0\% + 16{,}5\% = \mathbf{20,5}\ \%$$

All indicators related to nuclear are presented on Figure 9.

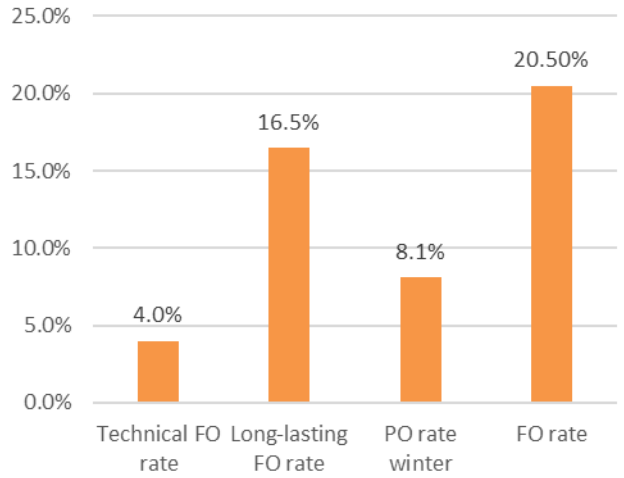


Figure 9: Overview of nuclear outage rates

[11] http://www.ejustice.just.fgov.be/eli/arrete/2022/09/09/2022042067/moniteur

6. Additional analysis

6.1 Seasonal distribution of forced outages per technology

Figure 10 shows the seasonal distribution of forced and planned outages. Forced outages occur in all seasons and no clear distinction can be made between the seasons. As such Elia proposes to keep using 1 forced outage rate per technology which is applicable for the whole year as was done in previous studies.

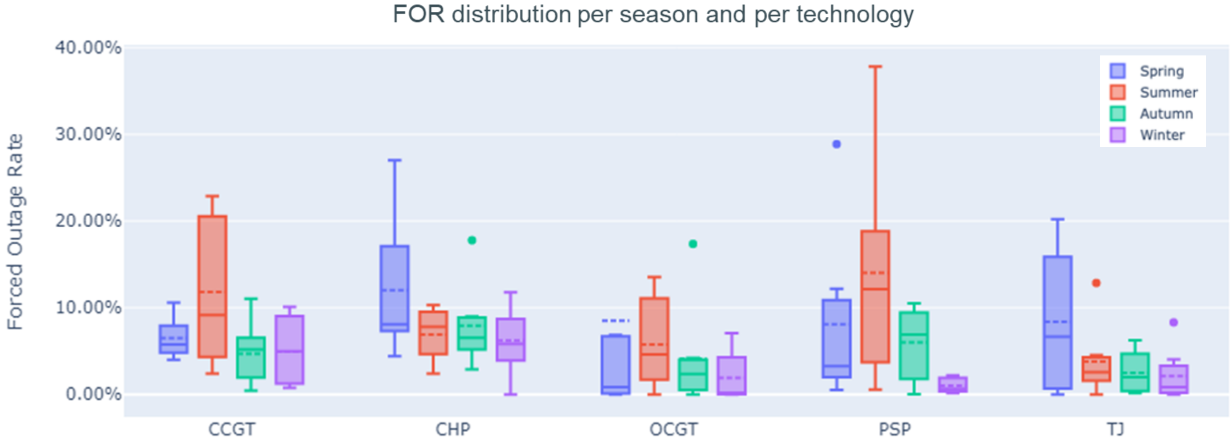


Figure 10: Seasonal distribution of forced outages per technology

6.2 Seasonal distribution of planned outages per technology

As can be observed on Figure 11, planned outages rates are lower during the winter but are still present. Note that Elia considers the winter period as from the November 1st until April 1st. Even though it is clear that planned outages do occur during these months, Elia proposes not to change its assumption that no planned outages occur on generation units in this period, even if this assumption might underestimate the potential gap in Belgium.

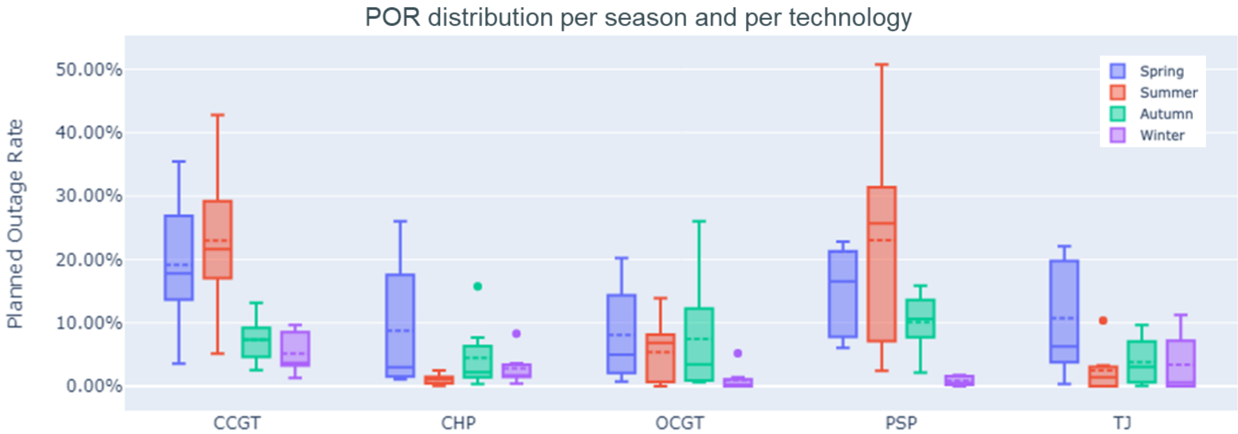


Figure 11: Seasonal distribution of planned outages per technology

6.3 Distribution of forced outage rates for different unit sizes of CCGT

As can be observed on Figure 12, unit size does affect the forced outage rate of CCGT units. However, no linear pattern can be observed and thus Elia proposes to keep using 1 forced outage rate for CCGT units. For the other capacity types, not enough units of the different sizes were available in order to provide a statistically robust analysis.

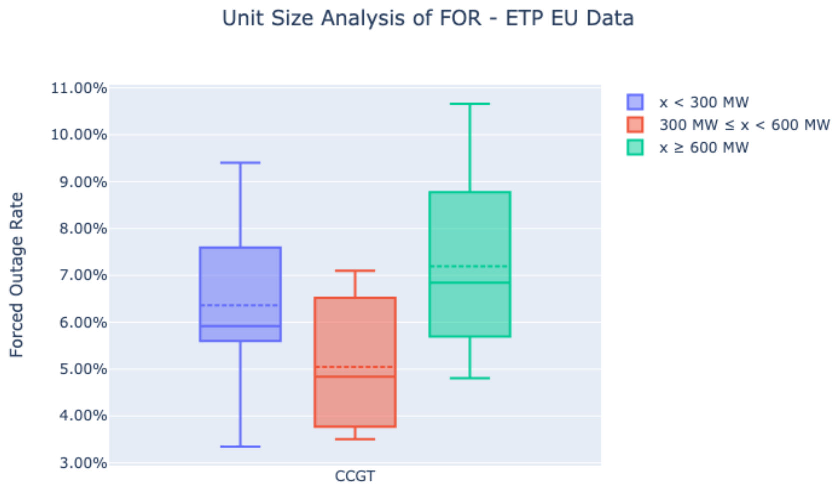


Figure 12: Distribution of forced outage rates for different unit sizes of CCGT

6.4 Distribution of forced outage rates for different unit ages for CCGT

As can be observed on Figure 13 unit age does affect the forced outage rate of CCGT units. However, there is only a significant difference for new capacities. No clear distinction can be observed between present and old CCGT's. Higher forced outage rates for new CCGT's seems counter-intuitive and Elia therefore proposes to keep using 1 forced outage rate for all different unit ages. For other capacity types, not enough units of the different ages were available in order to provide a statistically robust analysis.

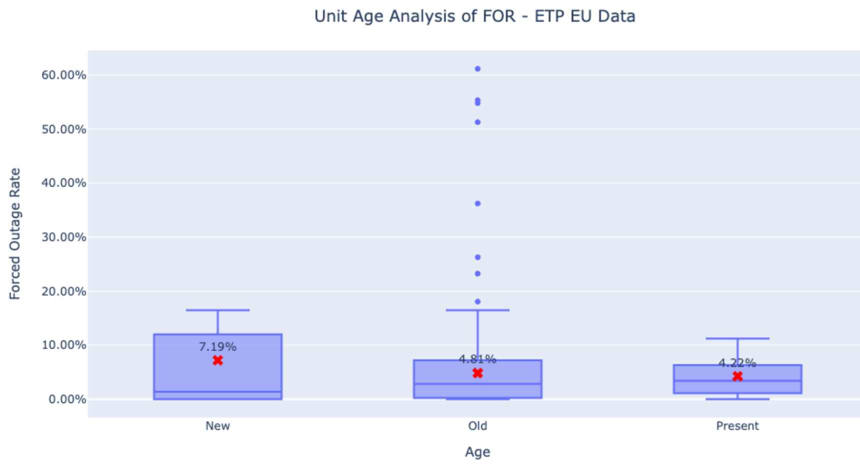


Figure 13: Distribution of forced outage rates for different unit ages for CCGT

7. Overview of the outage indicators to be used in the Adequacy & Flexibility study 2024-2034

This section gives a brief overview of the outage indicators to be used in the Adequacy & Flexibility study for 2024-2034 and a comparison with the values used in the Adequacy & Flexibility study for 2022-2032.

7.1 Overview of forced outage rates

The table and graph below show the overview of forced outage rates for all capacity types to be used in the Adequacy & Flexibility study 2024-2034.

Category	Average FO rate [%]	
	AdFlex 23	**AdFlex 21**
Nuclear	4.0 %* - 20.5%**	3.7%*
CCGT	5.5%	8.4%
OCGT	8.2%	9.2%
TJ	9.8%	3.6%
CHP, waste,	6.4%	7.0%
Pumped Storage	6.8%	4.5%
DC links (in each direction)	6.7%	6.0%

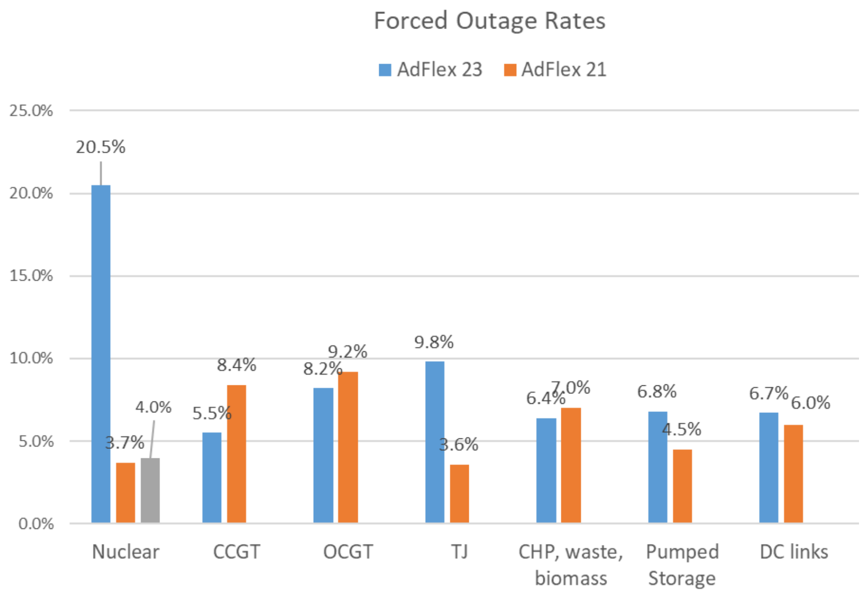


Figure 14: Overview of forced outage rates

** taking only technical forced outages into account*

*** taking technical and long-lasting forced outages into account*

7.2 Overview of number of forced outages per year

The table and graph below show the overview of the amount of forced outages per year for all capacity types to be used in the Adequacy & Flexibility study 2024-2034.

Category	Number of FO per year	
	AdFlex 23	**AdFlex 21**
Nuclear	1.3*	1.6*
CCGT	9.4	7.0
OCGT	9.2	3.1
TJ	3.2	2.0
CHP, waste,	2.9	3.8
Pumped Storage	6.7	3.0
DC links (in each direction)	1.9	2.0

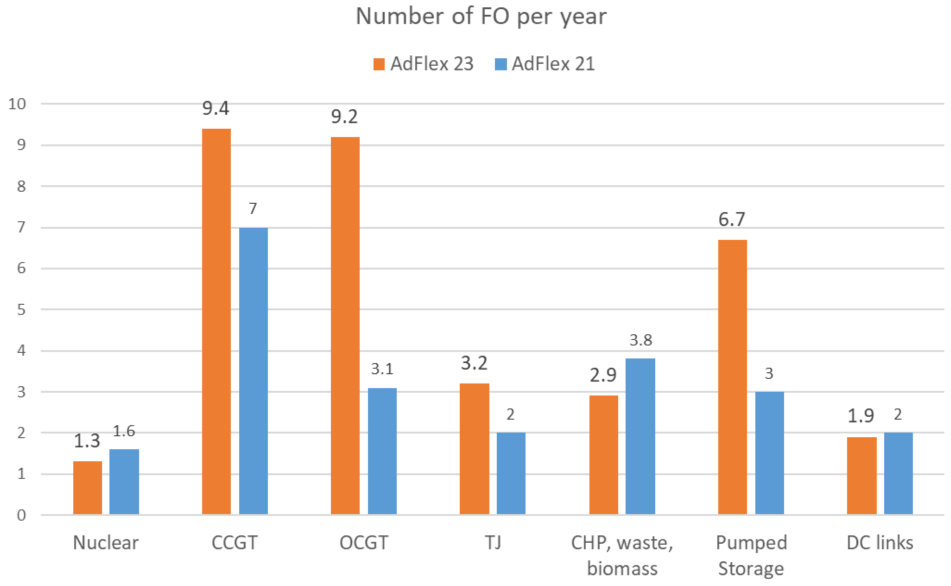


Figure 15: Overview of number of forced outages per year

** taking only technical forced outages into account*

7.3 Overview of average duration of forced outages

The table and graph below show the overview of the average duration of forced outages for all capacity types to be used in the Adequacy & Flexibility study 2024-2034.

Category	Average duration of FO rate [hours]	
	AdFlex 23	**AdFlex 21**
Nuclear	199*	240*
CCGT	110	101
OCGT	221	201
TJ	130	82
CHP, waste,	111	124
Pumped Storage	179	181
DC links (in each direction)	158	168

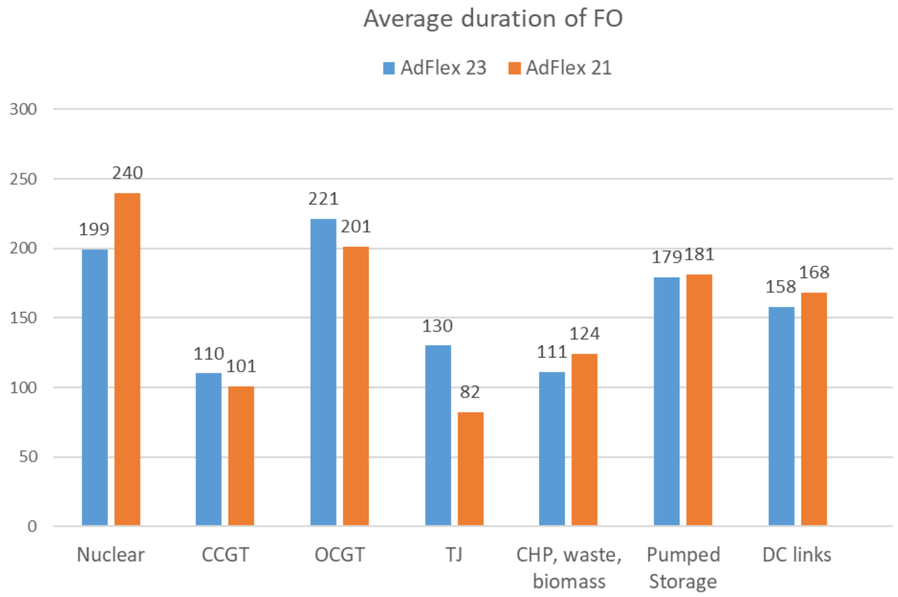


Figure 16: Overview of average duration of forced outages

** taking only technical forced outages into account*

8. Appendix: Elements to determine for the availability of the Belgian nuclear units (done by Elia)

8.1 Methodology applied for determining the availability of Belgian nuclear power in previous adequacy assessments

The availability of nuclear units used in the 'CENTRAL' scenario of the Adequacy & Flexibility studies was based on the following categorization[12]:

- **Planned maintenance** based on expected planning (REMIT data). This was precisely modelled by taking into account the exact dates foreseen for each unit for each year;
- **Forced outages**
  - **'Technical' Forced Outages**. These outages were taken into account with a force outage rate based on historical values;
  - **'Long-lasting' Forced Outages**: additional unavailability not covered by the two previous categories which are unpredictable and result in long-lasting events. Those events are based on the information and communication available on the AFCN/FANC website[13].

In the framework of the Adequacy & Flexibility study from June 2021, the additional unavailability due to 'long-lasting' forced outages for nuclear units was expressed in [GW]. This annex aims to provide an equivalent value in [%] for these events to better reflect the contribution of the technology to security of supply.

8.2 Determining the availability of Belgian nuclear units

Nuclear units being thermal with daily schedule CMUs, their availability is calculated based on an average of 10-year availability data. Regarding availability of nuclear power plants, 4 independent and cumulative statuses can be distinguished, considering that forced outages could be split between 'technical' and 'long-lasting' forced outages:

- The unit was **available** (presented as "Available" in §8.4).
- The unit was in a **planned outage**. A planned outage is considered as usual maintenance but also includes longer planned maintenance periods needed to solve issues encountered after a 'long-lasting' forced outage (presented as "Planned Unavailability" in the analysis in Annex). Regular maintenance is assumed to be performed outside of the critical periods for security of supply even though some planned outage events have been observed during winter based on historical data. Note that planned outage also includes the long-term operations (LTO) outage periods which are significantly longer than regular planned outage periods.
- The unit was in **'technical' forced outage**. A 'technical' forced outage is usually an unexpected event or malfunction leading to the shutdown of the unit in order to fix a well-defined and limited issue (presented as "Technical Force Outage" in §8.4). Those events are assumed to be independent from the climatic conditions.

The unit was in a '**long-lasting' forced outage**. A long-lasting forced outage is an unpredictable event, leading to a long-lasting shutdown of the unit (presented as "Long-lasting Force Outage" in §8.4). Those

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[12] A small adaptation was performed by changing 'additional unavailability' to 'long-lasting' forced outages and by grouping the two last category into a single 'forced outages' naming.

[13] https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique

events are assumed, similar to ‘technical’ forced outages, to be independent from the climatic conditions, meaning that it could happen anytime during the year and hence impact security of supply. This assumption is confirmed by looking at historical data. Note however that longer planned outages required to fix these long-lasting events are not considered in this category. The split between ‘long-lasting’ forced outage and longer planned outages required to fix those is based on information of AFNC/FANC website and on a case by case analysis on planned outages of the different nuclear units. More details can be found in “Details on unit per unit type of historical availability events”.

METHODOLOGY

The ‘technical’ forced outage (TFO) rates were already calculated in the framework of the Adequacy and flexibility study 2021 as explained above.

In order to calculate the rates of the planned and ‘long-lasting’ forced outages, historical daily nomination data were used for the period 2012-2021.

Regarding ‘long-lasting’ forced outages (LLFO), the following formula is used in order to calculate the corresponding rate:

$$'Long\ lasting'\ FO\ rate = \frac{(TFO\ energy\ \ + LLFO\ energy)2012 \rightarrow 2021}{(TFO\ energy + LLFO\ energy + Available\ energy)2012 \rightarrow 2021} - 'Technical'\ FO\ rate$$

Finally, the planned outage rate is calculated as the planned unavailability on the total period:

$$PO\ rate = \frac{PO\ days\ 2012 \rightarrow 2021}{Total\ days\ 2012 \rightarrow 2021}$$

Note that ‘technical’ forced outages, ‘long-lasting’ forced outages and planned outages should be considered as independent and cumulative.

EVENTS CONSIDERED AS 'LONG-LASTING' FORCED OUTAGE

Regarding 'long-lasting' forced outages, a defined number of events were considered, based on information available on AFCN/FANC website:

1. Indications of microflakes in the nuclear vessel of Doel 3 and Tihange 2[14] ;
2. Doel 4 sabotage[15] ;
3. Concrete degradation on bunkers of Doel and Tihange (D3/D4/T2/T3)[16] ;
4. Concrete issue during LTO on Tihange 1[17].

The unit-by-unit details are presented in "Details on unit per unit type of historical availability events".

HISTORICAL AVAILABILITY OF NUCLEAR UNITS

The different indicators are calculated based on the methodology set in the Royal Decree and according to the output of the CRM calibration report. It means that they were calculated:

- On the same 10-years historical availability data as for the CRM calibration report (meaning from 2012 to 2021 included);
- Based on the forced outage rate (including both 'technical' and 'long-lasting' forced outages);
- For all units of the same technology in-the-market during the studied timeframe.

By considering both 'technical' forced outage and 'long-lasting' forced outage, a forced outage rate of 20,5% is determined:

$$FO\ rate = 'Technical'\ FO\ rate + 'long-lasting' FO\ rate = \mathbf{4,0 + 16,5}\% = \mathbf{20,5}\%\ [\%]$$

Note that the 'technical' forced outages value is in line with the 'unplanned capacity loss factor' calculated by IAEA at world level[18].

However, based on the data observed from historical analysis, some planned outages during winter periods were observed, which is in contradiction with the philosophy of the derating factor, as described in the initial design notes[19]. Therefore, it could be considered fair to also consider the planned outage rate. While forced outage rates are assumed to be independent from climatic conditions and therefore calculated on the whole year (which is confirmed by historical data), planned outage is mainly foreseen outside of winter periods. Therefore, this additional indicator is only calculated on winter periods.

$$PO\ rate = \frac{PO\ days\ in\ winter\ 2012 \rightarrow 2021}{Total\ days\ in\ winter\ 2012 \rightarrow 2021} = \mathbf{8,1}\ [\%]$$

Those parameters can be converted in an equivalent availability for the nuclear technology. Based on previous results and considerations, an equivalent forced outage for nuclear between 4% and 28,6% could be considered.

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14 https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/actualite/indications-de-defauts-dans-les-cuves-des
15 https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/actualite/sabotage-de-la-turbine-vapeur-de-doel-4
16 https://fanc.fgov.be/nl/dossiers/kerncentrales-belgie/actualiteit/betondegradatie-doel-en-tihange
17 https://afcn.fgov.be/fr/actualites/lafcn-donne-son-feu-vert-au-redemarrage-de-tihange-1-0
18 https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinUnplannedCapabilityLossFactor.aspx
19 https://www.elia.be/-/media/project/elia/elia-site/users-group/ug/tf-crm/2020/crm-updated-design-notes---march-2020---all---clean-version.pdf

DISCUSSION ON THE RESULTS AND ADDITIONAL CONSIDERATIONS

The results presented above were calculated on the average over the last 10 years and for all nuclear units.

First, it is important to mention that **Doel 4 and Tihange 3 units are more recent** and hence could experience less outages than older units but one should also take into account the fact that those units would be extended beyond 40 years (as were some of the units considered in the dataset) and that the works associated to future LTO on these units might also lead to either extended planned outage or 'long-lasting' forced outage due to the analysis performed or to the critical operations to be performed. As also found in the historical data, 'long-lasting' forced outages also happened on those 2 most recent units.

It is also important to note that average values do not include the **discretionary impact that 'forced long-lasting events' can have**. When those events happen, their impact is corresponding to the size of the unit. This is different when looking at other types of units where there are more units but also generally of smaller size.

While planned maintenance is usually performed outside of winter and therefore should not be considered based on the Royal Decree methodology, the analysis has demonstrated that **it is not excluded that some nuclear units have to perform maintenances during winter**. Indeed, nuclear units might be subject to other constraints than other thermal units. When there is no view yet on the maintenance works planning (which is the case for a Y-4 auction) and also given the uncertainty on the LTO works that might be required, taking into account the planned maintenance historically observed during winter as part of an equivalent forced outage rate is a way to take that risk into account.

The so-called **'common mode' failures** of the units are not explicitly taken into account in the analysis as the values provided only look at averages. Some 'forced long-lasting' events can have an impact on more than one nuclear unit. Indeed, given the similar conception of those, any anomaly found in one unit can be also found in another one. This was already the case in Belgium (microflakes, concrete degradation on bunker buildings) but also in France where such events did happen several times. Combined with the discretionary nature of those events, the impact on the contribution of nuclear to adequacy is exacerbated.

In addition, it will be key to take the most up to date information when calculating future availability for the nuclear units. That should include the maintenance planning or works (if known) but also new risks not covered by the present analysis (if they arise in the future).

8.3 Conclusion

Based on the results as summarized on Figure 17, the availability of Belgian nuclear units could be fixed between 71,4% and 96%, depending on the independent and cumulative parameters considered: ‘technical’ forced outages, ‘long-lasting’ forced outages and planned outages during winter periods.

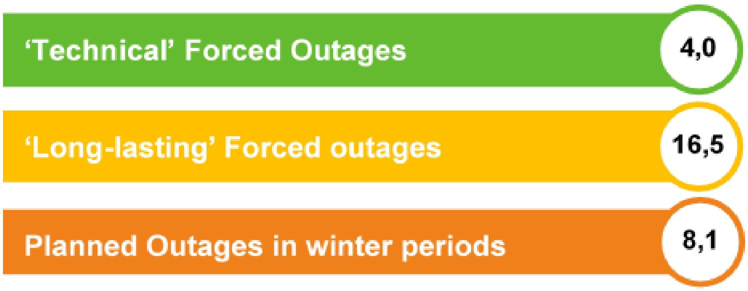


Figure 17: Outage Rates [in %] that could be considered for an equivalent forced outage for nuclear technology

8.4 Details on unit per unit type of historical availability events

The following sections detail the choices made for each past event considered in the dataset. Different periods are considered in the different graphs:

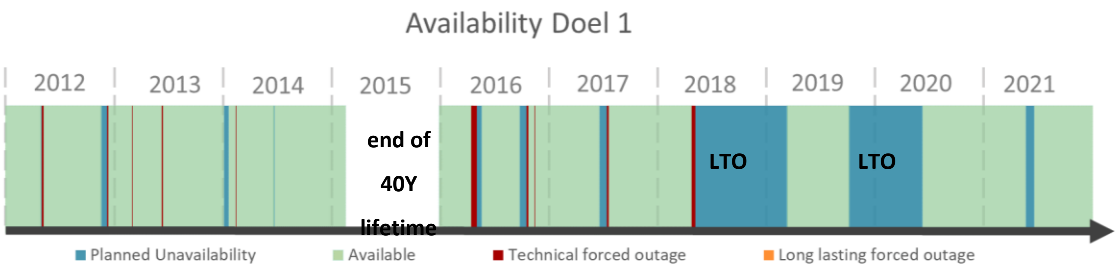
- Periods when the unit is available (in green);
- Periods when the unit is in planned outage (in blue);
- Periods when the unit is in forced outage (in yellow);
- Periods when the unit is in long-lasting forced outage (in red).

The different graphs also indicate the periods when the unit was decoupled from the electricity network (Doel 1), periods when the unit was stopped for LTO works and the details of the issue encountered when a period with long-lasting forced outage is observed.

DOEL 1

Remarks regarding Doel 1 availability:

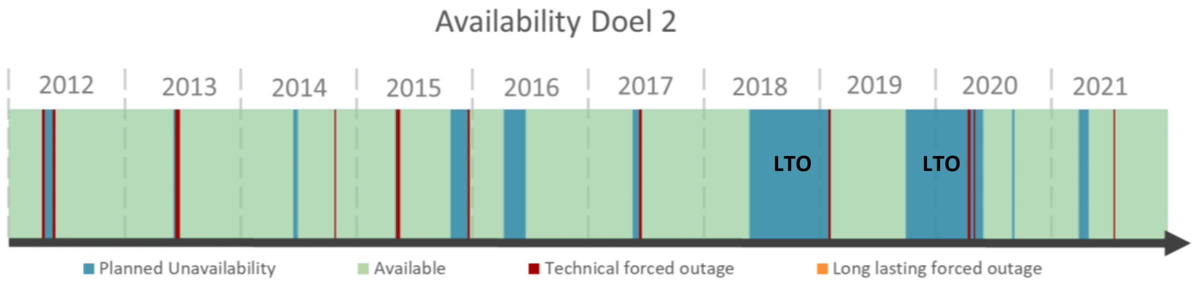
- Doel 1 40-years lifetime ended in February 2015. The unit was then stopped during some months before the political decision was taken to extend its lifetime to 50 years;
- 2 long planned unavailability periods happened from 2018 to Q2 2020 and are linked to the operations and maintenance related to the LTO;
- No long-lasting forced outages were taken into account.



DOEL 2

Remarks regarding Doel 2 availability:

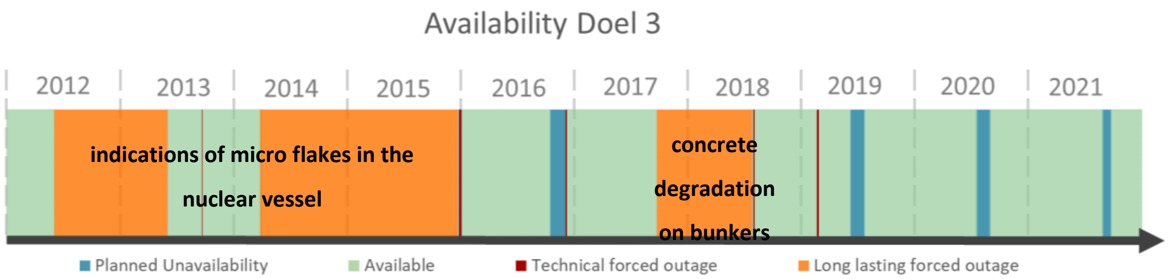
- Doel 1 40-years lifetime was supposed to end in November 2015 but its lifetime was extended to 50 years after political decision;
- 2 long planned unavailability periods happened from 2018 to Q2 2020 and are linked to the operations and maintenance related to the LTO;
- No long-lasting forced outage were taken into account.



DOEL 3

Remarks regarding Doel 3 availability:

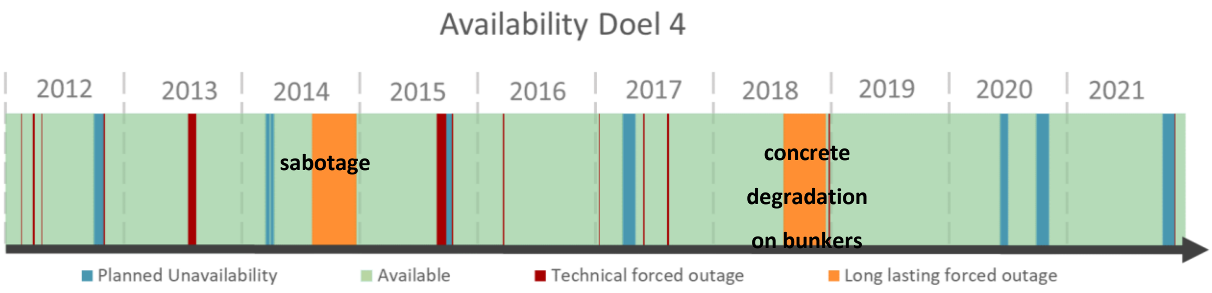
- 2 long-lasting forced outage are considered in 2012-2013 and 2014-2016 related to the indications of microflakes in the nuclear vessel;
- 1 long-lasting forced outage period is considered from 2017 to 2018 related to concrete degradation on bunkers.



DOEL 4

Remarks regarding Doel 4 availability:

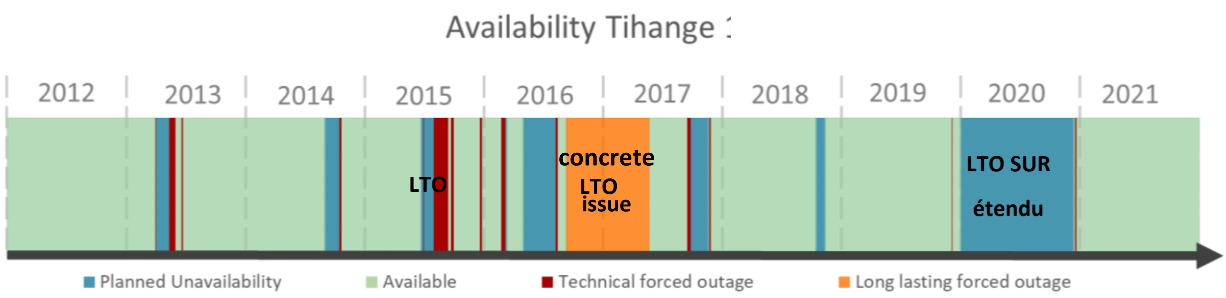
- 1 long-lasting forced outage period is considered in 2014 due to a sabotage;
- 1 long-lasting forced outage period is considered in 2019 related to concrete degradation on bunkers.



TIHANGE 1

Remarks regarding Tihange 1 availability:

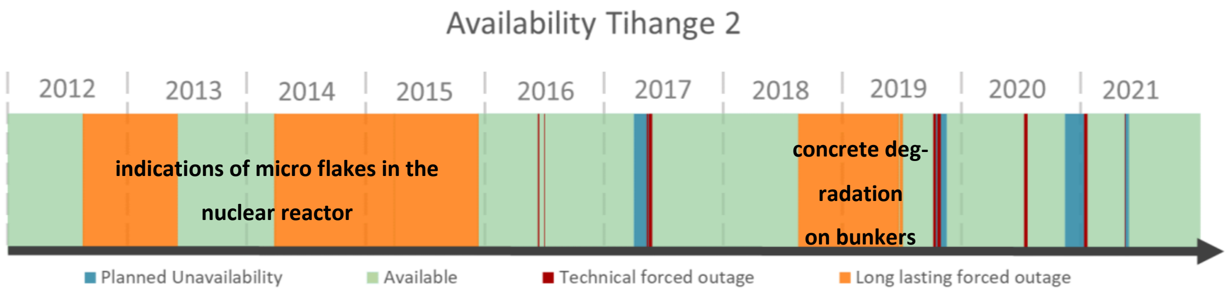
- 1 long-lasting forced outage period is considered in 2016 to 2017 due to a concrete issue on a safety building;
- 3 periods linked to the operations and maintenance related to the LTO are considered, including the last one regarding the commissioning of the "SUR étendu" building.



TIHANGE 2

Remarks regarding Tihange 2 availability:

- 2 long-lasting forced outage periods are considered in 2012-2013 and 2014-2016 related to the indications of microflakes in the nuclear vessel;
- 1 long-lasting forced outage period is considered from 2018 to 2019 related to concrete degradation on bunkers.



TIHANGE 3

Remarks regarding Tihange 3 availability:

- 1 long-lasting forced outage period is considered in 2018 related to concrete degradation on bunkers;
- 1 long period of planned unavailability considered in 2020 related to extra-work required to repair the concrete degradation on bunkers.