All CE and Nordic TSOs' results of CBA in accordance with Art.156(11) of the Commission Regulation (EU) 2017/1485 of 2 August 2017

- Final Report -

29 May 2020

1. Contents

2. Disclaimer

This report presents the CBA approved Methodology, the results of the CBA analysis and details the pros and cons of all possible options of minimum activation time period for both Continental Europe and Nordic. The results have been submitted for public consultation from 27 February 2020 until 30 April 2020.

3. Reference and Acronyms

CBA	Cost Benefit Analysis compliant with the requirements contained in Article 156(11) of Commission Regulation (EU) 2017/1485 of 2 August 2017
SA	Synchronous Area
DFD	Deterministic Frequency Deviations
LL	Long Lasting frequency deviation events
CE	Continental Europe Synchronous Area
Nordic	Nordic Synchronous Area
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
FAT	Full Activation Time of FRR
LER	FCR providers with Limited Energy Reservoir
TminLER	As of triggering the alert state and during the alert state, time for which each FCR provider shall ensure that its FCR providing units with limited energy reservoirs are able to fully activate FCR continuously
SOC	State of Charge of LER
MaxSSdf	Maximum Steady State frequency deviation (0.2 Hz in CE and 0.5 Hz in the Nordic)

[1] All Continental Europe and Nordic TSOs' proposal for assumptions and a Cost Benefit Analysis methodology in accordance with Article 156(11) of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation.

[2] Explanatory document of the proposal for assumptions and methodology for a Cost Benefit Analysis (CBA) compliant with the requirements contained in Article 156(11) of Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (System Operation Guideline Regulation – SOGR)

[3] COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation.

[4] FCR provision by Limited Energy Reservoirs - Focus on approach and collection of inputs – Updated version (https://www.entsoe.eu/events/2019/11/15/webinar-on-cba-to-assess-the-time-period-required-for-fcr-with-limited-energy-reservoirs-lers/)

4. Background

This document is aiming at reporting the results of the Cost Benefit Analysis carried out by all Continental Europe and Nordic TSO's in accordance with the requirements contained in Article 156(11) of Commission Regulation 2017/1485 of 2 august 2017.

In March 2019 all TSOs of the CE and Nordic synchronous areas have submitted for regulatory approval assumptions and methodology for the CBA to be conducted, in order to assess the time period required for FCR providing units or groups with limited energy reservoirs to remain available during alert state.

All Nordic NRAs have approved the assumptions and methodology for the CBA on 16th April 2019, whereas all CE NRAs have given their approval on 23rd May 2019.

All the assumptions regarding the input data and the methodology to be used to undertake the CBA are described in [1] and [2].

Article 156(11) provides that by 12 months after all NRAs approval, all TSO's of the CE and Nordic synchronous areas are requested to submit the results of the CBA to the regulatory authorities.

5. General information on the methodology

According to [1] and [2] the CBA analyses a set of scenarios. For each synchronous area, the scenarios are defined considering the following criteria:

- Different TminLER: 15 min, 20 min, 25 min and 30 min.
- Different share of LER[1] in the FCR provision: from 0% to 100% with 10% steps.
- Presence or absence of mitigation action against the DFD.

Given the previous criteria, a total number of 88 scenarios have been investigated.

According to [1] and [2] the CBA is based on a probabilistic approach. For each synchronous area and each scenario, the probabilistic dimensioning of FCR needed to avoid critical LER depletions[2] is calculated. To each dimensioned FCR a cost is associated; it is divided in cost due to LER and cost due to non-LER.

The procedure adopted to calculate the needed FCR in each scenario and the resultant costs is shown in the Figure 1.

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[1] The LER share is referred to the proportion of LER amongst the FCR provider selected to fulfil the requirements. E.g.: a LER share equal to 50% in CE with a FCR requirement of 3000 MW means that 1500 MW of FCR are given by LER.

[2] According to [1], a critical LER depletion is a condition in which occur both a LER depletion (reservoir completely empty or completely full) and an exceeding of steady state frequency deviation over the maximum steady state frequency deviation as defined in [3] Annex III Table 1.

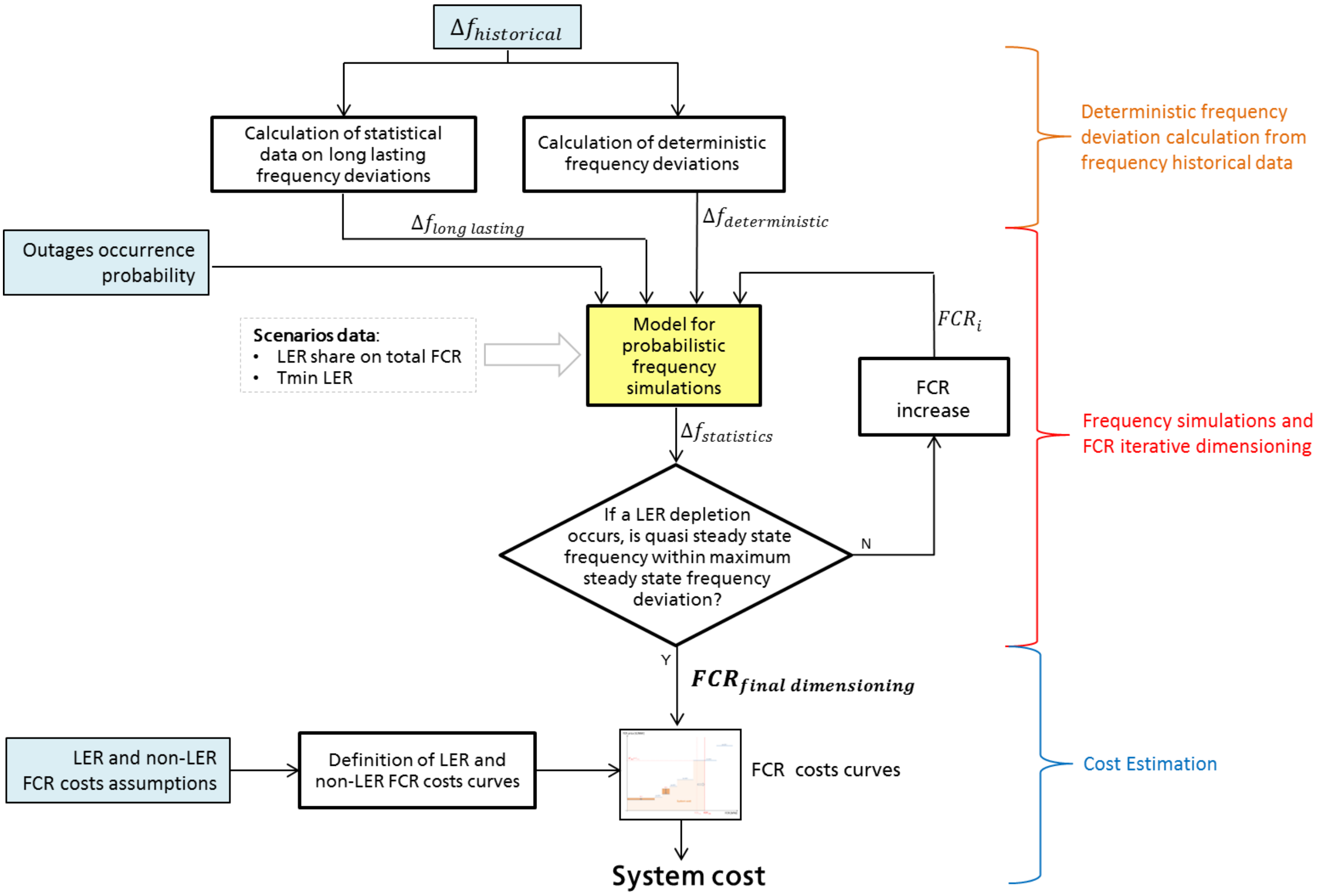

Figure 1 The calculation process for the needed FCR in each scenario and the resultant costs

The previous diagram shows in light blue the input[3]:

- historical frequency deviations;
- occurrence probability of outages leading to loss of production in the system;
- assumptions on FCR costs for both LER and non-LER providers.

Further information on the input data used in the methodology are provided in [4].

As shown in Figure 1, the procedure is based on a probabilistic frequency simulation model to verify if it is possible a critical depletion in the system. This probabilistic model exploits a Monte Carlo methodology: it simulates a large number of working conditions for the power system, randomly extracting the occurrence of outages and frequency deviations patterns due to long lasting events and DFD.

The results presented in this report are associated with Monte Carlo simulations over a working period of the system of 200 years. It means the Monte Carlo model has simulated 200 different years of work; in each year a different set of random extractions is performed.

The simulated frequency deviation trends - resulting from the randomly extracted outages, DFD and LL - are calculated by mean of a simplified simulation model whose assumptions are described in [1] and [2].

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[3] A detailed description of the meaning of each input can be found in [1] and [2].

The main parameters adopted for the analysis presented in this report are sum up in the following list.

- **Starting FCR value**: 3000 MW for CE – 2050 MW for Nordic
  It is the current dimensioning value for FCR. If the model detects a critical depletion, the iterative increase of FCR starts from this value.
- **FCR increase step**: 100 MW for CE – 50 MW for Nordic.
  It is the iterative increase step for FCR.
- **FAT**: 10.5 min for CE – 12.1 min for Nordic.
  The FRR is simulated considering a simplified single centralized controller for each synchronous area which operates only to restore the frequency deviation to 0 mHz. The FAT value affects how fast the controller operates.
- **Recharge time**: 120 minutes for both synchronous areas.
  It represents the time needed for LER to completely recover from depletion conditions (either full or empty). After a depletion, it is the time needed to reach the condition such that state of charge is equal to 50% of the reservoir.
- **Minutes around change of hour (DFD)**: 5 minutes for both synchronous areas.
  For both synchronous areas the DFD are considered within an interval of ±5 minutes around the change of the hour.
- **DFD Mitigation coefficient**: 0.8 for both synchronous areas.
  For both synchronous areas, the scenarios with mitigation actions on DFDs are calculated reducing the current DFD of a factor equal to 0.8. The reduction factor for DFDs results in a reduction in amplitude of the associated frequency deviations. The DFDs used as input for the model in the scenarios with DFDs reduction have an amplitude equal to 80% of DFDs in the scenarios without reduction.

According to [1], the simplified simulation model has been used also for testing all the scenarios against a set of most relevant frequency events actually occurred in the past.

For Nordic the two worst significant frequency deviations have been tested; they occurred on:

- 03/10/2011 h 21-23;
- 09/05/2018 h 00-02.

6. Results for Nordic synchronous area

Results of the probabilistic analysis

FCR dimensioning

The results in terms of FCR needed to avoid critical depletion are presented in the Table 1.

The scenarios are organized in a matrix having different TminLER on the rows and different LER share on the columns.

Table 1: FCR required to avoid critical depletions in Nordic [MW]

	LER share										
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
15'	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2200**	**2400**	**2400**	**2400**	**2400**
20'	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2200**	**2200**	**2200**	**2200**	**2200**
25'	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**
30'	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**	**2050**

The results with and without DFD mitigation actions are completely the same.

Costs associated to increased FCR

The costs for providing FCR along a year in each scenario are shown in the following Table 2 (the values are in M€/year).

The Table 3 and Table 4 show respectively the costs due to non-LER and the costs due to LER.

Table 2: Total yearly costs to provide FCR in Nordic [M€/year]

	LER share											
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15'	313.8	248.0	194.2	140.3	86.5	61.0	77.8	102.2	118.6	134.9	151.2	148.0
20'	313.8	252.1	199.0	145.9	92.8	68.0	85.8	101.5	117.2	132.9	148.6	150.7
25'	313.8	256.7	204.2	151.7	99.3	75.1	87.1	102.3	117.6	132.9	148.2	153.5
30'	313.8	261.6	209.8	158.0	106.2	82.6	95.3	111.2	127.1	143.1	159.0	160.7
Mean	313.8	254.6	201.8	149.0	96.2	71.7	86.5	104.3	120.1	135.9	151.8	

Table 3: Yearly costs to provide FCR in Nordic due to non-LER [M€/year]

	LER share											
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15'	313.8	246.0	178.3	110.5	42.8	3.3	0.0	0.0	0.0	0.0	0.0	81.3
20'	313.8	246.0	178.3	110.5	42.8	3.3	0.0	0.0	0.0	0.0	0.0	81.3
25'	313.8	246.0	178.3	110.5	42.8	3.3	0.0	0.0	0.0	0.0	0.0	81.3
30	313.8	246.0	178.3	110.5	42.8	3.3	0.0	0.0	0.0	0.0	0.0	81.3
Mean	313.8	246.0	178.3	110.5	42.8	3.3	0.0	0.0	0.0	0.0	0.0	

Table 4: Yearly costs to provide FCR in Nordic due to LER [M€/year]

	LER share											
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15'	0.0	1.9	15.9	29.8	43.8	57.7	77.8	102.2	118.6	134.9	151.2	66.7
20'	0.0	6.1	20.8	35.4	50.0	64.7	85.7	101.5	117.2	132.9	148.6	69.4
25'	0.0	10.6	25.9	41.2	56.5	71.8	87.1	102.3	117.6	132.9	148.2	72.2
30'	0.0	15.5	31.5	47.4	63.4	79.3	95.3	111.2	127.1	143.1	159.0	79.4
Mean	0.0	8.6	23.5	38.5	53.4	68.4	86.5	104.3	120.1	135.9	151.8	

Yearly average LER depletions

The yearly average number of depletion that occur for each scenario are presented in the following Table 5. The results are referred to simulations in which the FCR requirement is not increased (FCR equal to 2050 MW).

Table 5: Yearly average depletion number in Nordic (with FCR = 2050 MW)

	LER share										
TminLER	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15'	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.82**	0.83
20'	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.10**	0.10
25'	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	0.00
30'	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	0.00
Mean	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	

The yearly average number of critical depletion without FCR increase (FCR equal to 2050 MW) is shown in Table 6.

Table 6: Yearly critical average depletion number in Nordic (with FCR = 2050 MW)

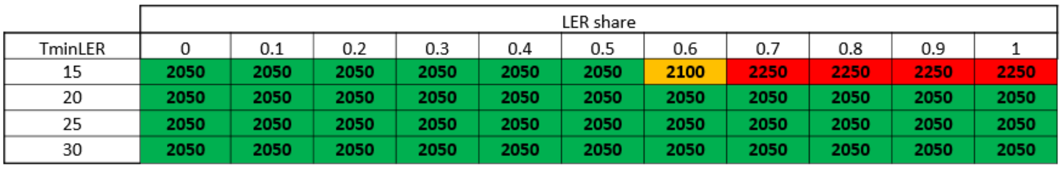
	LER share										
TminLER	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15	**0**	**0**	**0**	**0**	**0**	**0.14**	**0.68**	**0.76**	**0.83**	**0.83**	0.29
20	**0**	**0**	**0**	**0**	**0**	**0.04**	**0.10**	**0.10**	**0.10**	**0.10**	0.04
25	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	0
30	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	0
Mean	0	0	0	0	0	0.04	0.20	0.22	0.23	0.23	

Results of the test against the most relevant events

In the Nordic synchronous area, the only tested events are the two worst recorded events.

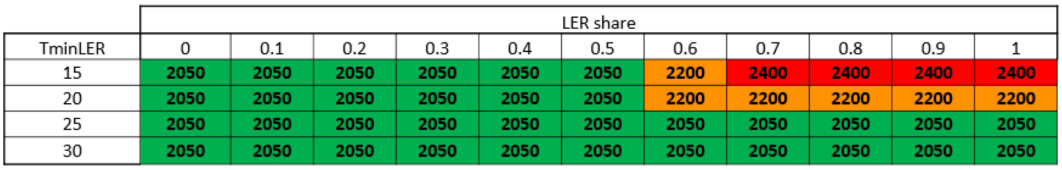
The results are shown in the following Table 7.

Table 7: Results of most relevant event tests on Nordic system [MW]



	LER share										
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
15	2050	2050	2050	2050	2050	2050	2100	2250	2250	2250	2250
20	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050
25	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050
30	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050

Event
03/10/2011 h21:09



	LER share										
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
15	2050	2050	2050	2050	2050	2050	2200	2400	2400	2400	2400
20	2050	2050	2050	2050	2050	2050	2200	2200	2200	2200	2200
25	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050
30	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050

Event
09/05/2019 h00:26

The most relevant results do not provide any further information in addition to the output of the probabilistic approach.

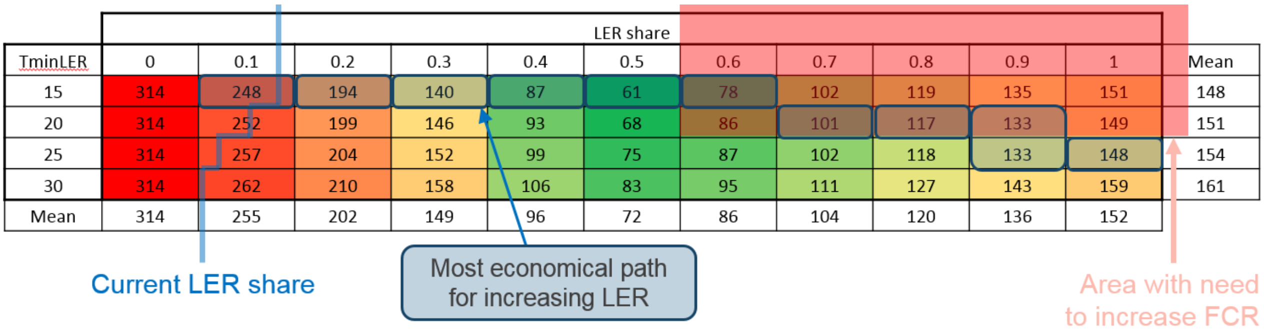
7. Minimum activation time period for Nordic

The current installed LER in Nordic is about:

- 177 MW with TminLER of 15 minutes (8.6 % LER share);
- 120 MW with TminLER of 20 minutes (5.9 % LER share);
- 62 MW with TminLER of 25 minutes (3.0 % LER share);
- 5 MW with TminLER of 30minutes (0.2 % LER share).

The dependence of installed LER from TminLER is mainly due to run-of-river in Norway.

The situation in terms of current LER share is shown in Figure 2.



	LER share											
TminLER	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Mean
15	314	248	194	140	87	61	78	102	119	135	151	148
20	314	252	199	146	93	68	86	101	117	133	149	151
25	314	257	204	152	99	75	87	102	118	133	148	154
30	314	262	210	158	106	83	95	111	127	143	159	161
Mean	314	255	202	149	96	72	86	104	120	136	152	

Figure 2: Current LER share in Nordic

Given the current situation the most economical solution is 15 minutes.

The current LER share is well below the thresholds above which an FCR increase is needed.

If the LER share exceeded 60% an FCR increase would be needed. In this situation the most economical solution depends on the LER share itself:

with 60%	15'
with 70%&80%	20'
with 90%	20'&25'
with 100%	25'

The differences between different scenarios costs are however very small.

The time period choice will only apply to FCR-D.

Minimum activation time period choice for Nordic synchronous area

Considering the results of the CBA and the current presence of LER in the Nordic synchronous area, the all Nordic TSOs proposal is to set 15 minutes minimum activation time period.

8. Consideration on the impact of the input on the results

In the following an overview of the effect of the different input on the final results is provided.

Each main category of input is briefly described and analysed and its effect on either the final FCR matrix and on the costs matrix is considered.

Frequency deviation

According to the methodology, the frequency deviation used as input by the Monte Carlo model are the historical Nordic and CE frequency trends.

According to Article 4(2) of [1], the historical frequency data have been analysed to elaborate statistics of both deterministic frequency deviations and long-lasting frequency events.

These statistics are then used for the random extractions made by the Monte Carlo model.

Long-lasting frequency deviation

Long lasting frequency events are events with an average steady state frequency deviation larger than the standard frequency range over a period longer than the time to restore frequency.

According to this definition, the historical frequency trends have been analysed to find out all the occurrence of this kind of conditions. The list of all the long-lasting events has been then used to define a statistics description of their occurrence (e.g. minutes in which they usually start).

These statistics are then used by Monte Carlo model to extract the long-lasting event to be simulated. A specific extraction of a long-lasting event by the Monte Carlo means that a single really-occurred long-lasting event is simulated in the model. The extraction of the events takes into account the years in which the long-lastings occurred: the most recent years are weighted more than the less recent ones.

The occurrence of long-lasting event in the Monte Carlo simulation (e.g. the number of long-lasting which are on average extracted in a simulated year) is roughly the same as the real occurrence of long-lasting (average number of long-lasting occurred in the system).

The long-lasting event are by far the input having the larger energy content amongst all the input; it means that the energy used by FCR to contain these event is usually larger than the energy used for containing outages and DFDs. Furthermore, the simulation model does not activate FRR to restore frequency during these event: this choice is related to the fact that the long-lasting event already implicitly contain the FRR action. One of the main reason for a long-lasting to occur is a problem in the FRR activation.

For the previous reasons, the long-lasting event are by far the most impacting input on the results in terms of final FCR needed to avoid critical depletion (and Table 1).

Deterministic frequency deviation

The deterministic frequency deviations are extracted from historical data around the change of hour (from minute 55 to minute 05). The Monte Carlo model extract deterministic frequency deviation weighting more the most recent data than the less recent ones.

Even if the deterministic frequency deviation can reach significant values, their energy contents is usually not very large thanks to their limited duration. For this reason, the impact of them to the depletion of LER is minimal. Even reducing the amplitude of extracted DFDs of a 0.8 factor, the final FCR needed values (**Error! Reference source not found.** and Table 1) do not change.

It is worth highlighting that DFDs and long-lasting extractions do not overlap each other. If a long-lasting is extracted, no DFDs is extracted as long as the long-lasting ends.

As for long-lastings, the simulation model does not activate FRR to restore frequency during DFDs: this choice is related to the fact that the DFDs already implicitly contain the FRR activation.

Outages

The outages are randomly extracted from a list of possible events (total or partial trip of generation units, trip of HVDC connecting a different synchronous area). The failure rates associated to different event categories have been provided in [4].

The energy content associated with the frequency deviation caused by an outage depends on the FRR FAT modelized in the simulation model. The FRR FAT are indicated in 0.

Considering the adopted FRR FATs and the failure rates, the energy content of the frequency deviation associated with outages is far less than the energy content of long-lasting. The impact on the results (in terms of FCR needed values) is minimal.

LER cost

The detail on how the costs associated to the LER have been defined are provided in [4].

The already existing LER have costs which do not consider the investment. The investment cost for them has been considered as a sunk cost. For them only the variable costs are taken into account (e.g. related to round trip efficiency and maintenance).

The newly installed LER have costs accounting for both investment and variable costs.

The effects of different approach on LER costs would obviously impact the max of overall costs (, , Table 2 and Table 4).

If the installation costs of LER decrease, the yearly costs to provide FCR due to LER would decrease only for the scenarios with LER share above the current situation. The already installed LER are not impacted by a change in the assumptions on installation costs.

If the OPEX of LER (e.g. maintenance) decrease, the yearly costs to provide FCR due to LER would decrease for all the scenarios.

It is important to highlight that, for the electrochemical storage (the reference technology of newly installed LER), the CAPEX costs do not increase proportionally with the increase of the energy-to-power ratio. The installation costs include elements independent from the energy capacity of the plant, such as power electronics, grid connection and civil work. Also the OPEX do not increase proportionally with energy-to-power ratio.

The impact of different assumptions in LER costs shall then be considered looking at all the different components: either the energy-dependant and the energy-independent.

Non LER cost

A detailed description of how the FCR provided by non-LER has been defined is provided in [4].

There are several factors that can impact the results in term of costs on non-LER, the main are:

- a change in the qualified FCR that the different technologies currently provide (e.g. related to decarbonisation).

- a change in the variable costs of traditional generation (e.g. variation of gas/oil/coal/CO_2 costs);
- a change in the energy price (day ahead markets).

It is important however to highlight that even if these changes would potentially change the non-LER costs curve, the impact on the final CBA results (, , Table 2 and Table 3) is not proportional and shall be investigated to understand the effects.

For example, a change in the energy price (while all the other factors are the same) would make cheaper some provider and more expensive other providers. It all depends on the shift of opportunity costs. Therefore, it's hard to know a-priori the effects of different non-LER assumptions on the yearly costs to provide FCR due to non-LER.

Furthermore, these effect occurs only for the part of the cost curve below the clearing point: the changes in costs of "expensive" FCR would not impact the final results.

9. Consideration on FCR Additional Properties - Art.154(2) of SOGL

The whole CBA has been realized without taking into account the FCR Additional Properties (Art.154(2) of [2]), which are currently in discussion and not enforced yet, and which will impact a series of regulatory and technical aspects (increase of aFRR dimensioning, costs to be associated, transitional period will be provided, how to deal with existing plants, impact on FCR availability of existing LER with 15'). As stated in the methodology, when relevant changes in the assumptions will occur, the CBA shall be accordingly run again.