UPDATED

FCR provision by Limited Energy Reservoirs

1

Focus on approach and collection of inputs
- **UPDATED** post webinar

04 December 2019
Rev.02 – post Stakeholders webinar

Webinar on the CBA assessment of the time period required for FCR providing units or groups with limited energy reservoirs to remain available during alert state

- The Webinar is related to the activity of Cost Benefit Analysis in accordance with Article 156(11) of the Commission Regulation (EU) 2017/1485 of 2 August 2017.
- The methodology «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» has been presented in a public dedicated WS and consulted.
- The methodology has been approved by Continental Europe and Nordic National Regulatory Authorities after a request for amendments.
- All TSO's have gathered all the data (both technical and economical) needed to perform the CBA in the months following the approval.

Webinar on the CBA assessment of the time period required for FCR providing units or groups with limited energy reservoirs to remain available during alert state

- The steps following the approval of the methodology and the input data collection activities has been shared in System Operation – Europan Stakeholder Committe during regular meetings.

This Webinar is then aiming at **presenting and discussing the input data of the CBA methodology**.

We kindly ask the audience to focus on the discussion of input data and, as long as possible, limit questions/comments on the CBA methodology.

1. Outages

2. Historical frequency deviations

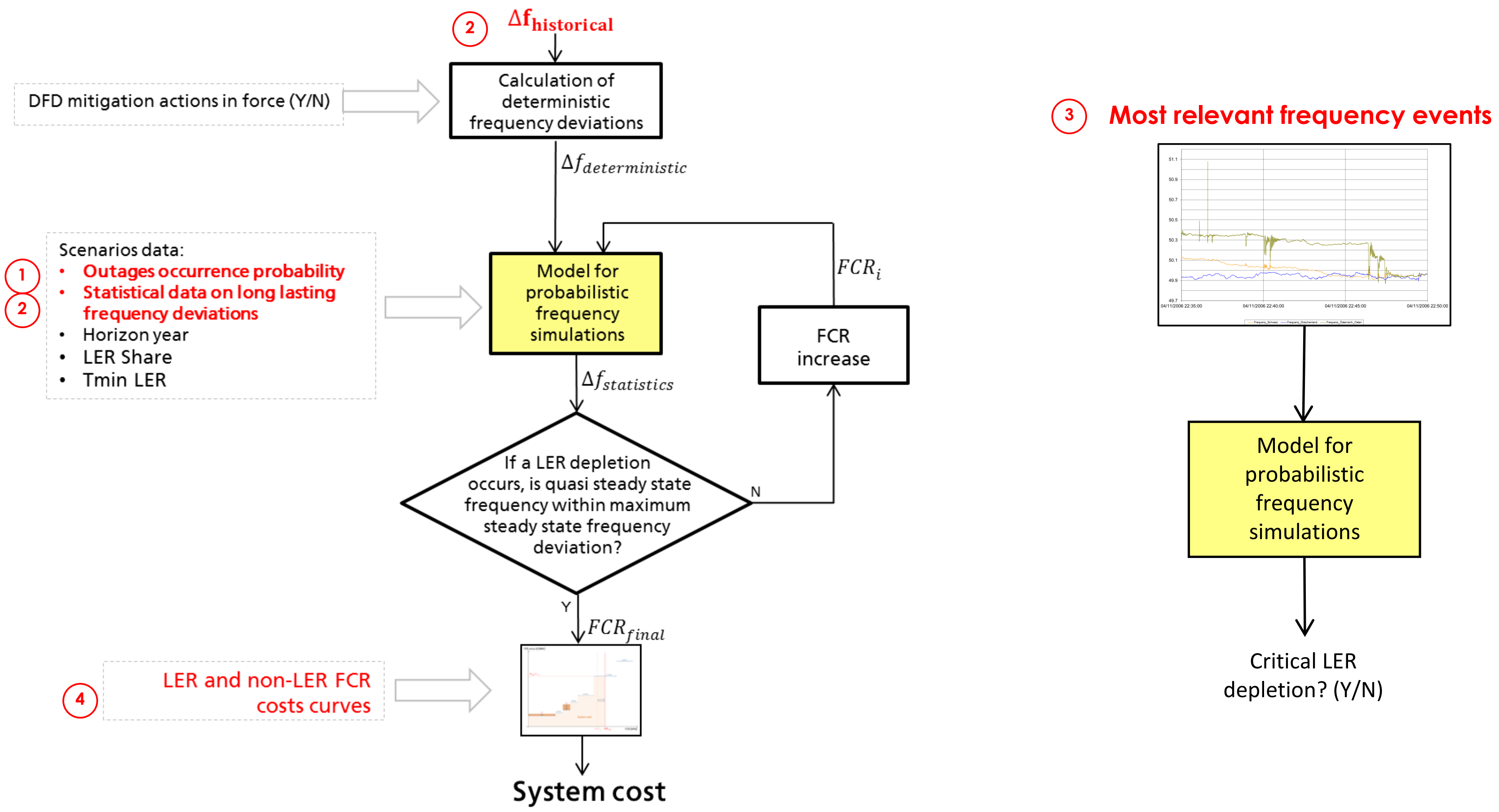
3. Most relevant frequency events

4. Cost of LER & non-LER

- For the development of the CBA 4 main type of inputs have been collected, analyzed and processed

Input type for the Monte Carlo model

Where do the input data are used in the simulation models?



1 Outages statistics

2 Historical Df

3 Most relevants events data

4 Costs (LER & non-LER)

The input shall be ***completely defined before the run*** of the simulations. Even a slight difference in the input implies the need of a complete re-run (with the consequent delay).

According to the approved Methodology, if the required input parameters will significantly change, all TSOs shall submit the results of an updated cost-benefit analysis

1. Outages

Data collection on failure rate of system/equipment potentially involved in frequency degradation

Outages – Event types considered

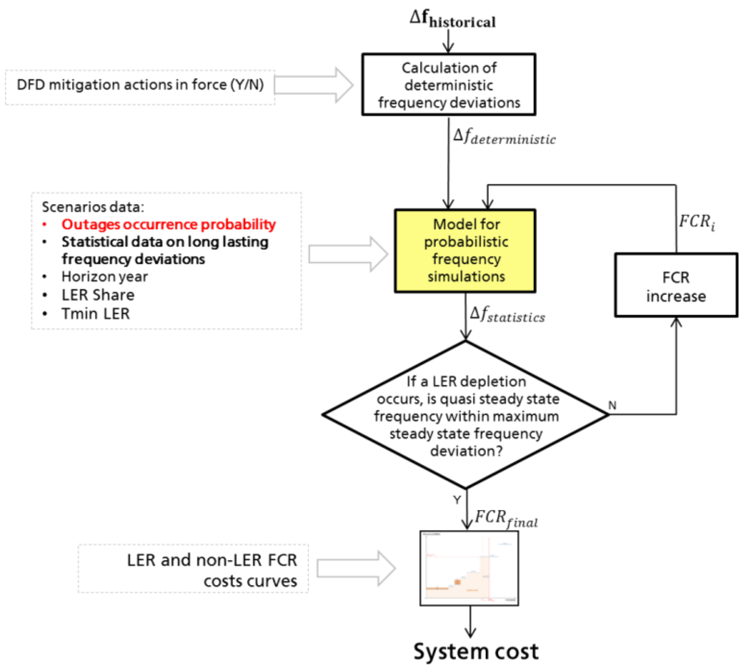
According to Article 4.2.c of the CBA methodology, the outages of relevant grid elements are one of the 3 sources of frequency disturbance used as inputs of the Probabilistic Simulation Model.

The outages taken into account are:

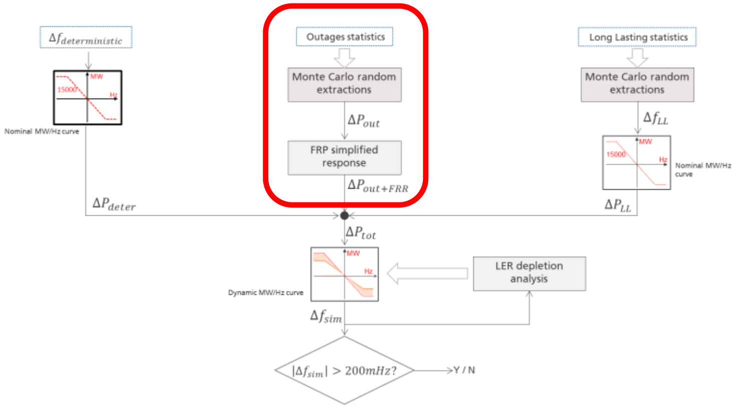
- **Failure on generation unit**
- **Failure on HVDC connection**

Are instead neglected the events related to:

- **Failure related to loss of load (due to critical busbar fault or critical substation blackout)**



Simulation model
Monte Carlo - Outages simulation and FRR effects



For each LFC area the FAT is the average of aFRR and mFRR, weighted on the typical aFRR and mFRR quantity:

$$FAT_{tot} = \frac{FAT_{aFRR} \cdot aFRR + FAT_{mFRR} \cdot mFRR}{aFRR + mFRR}$$

The synchronous area equivalent FAT is the average FAT of the single LFC areas, weighted for the k-factors:

$$FAT_{SA} = \frac{\sum_{i \in SA} k_i \cdot FAT_{tot,i}}{\sum_{i \in SA} k_i}$$

Unlimited FRR is considered

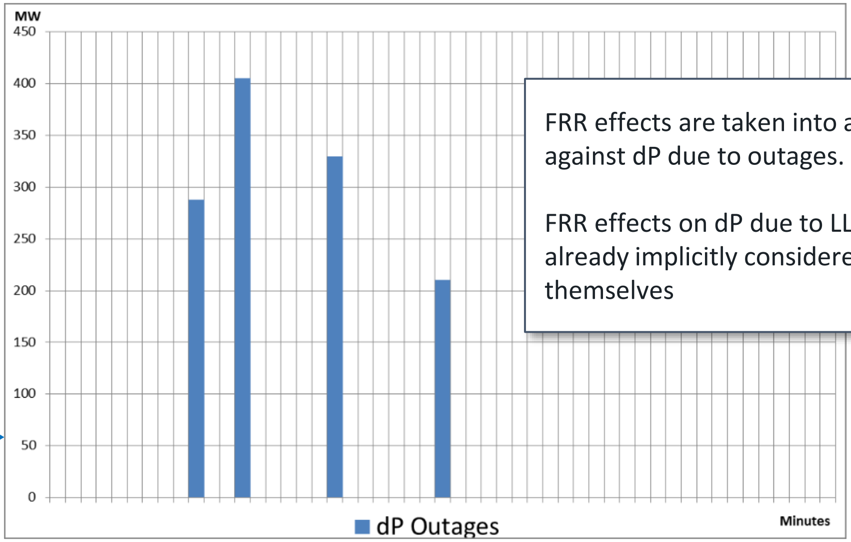
Outages statistics

Random extractions in each minute of outages. Concomitant outages are possible since all the events are stochastically independent.

ΔP_{out}

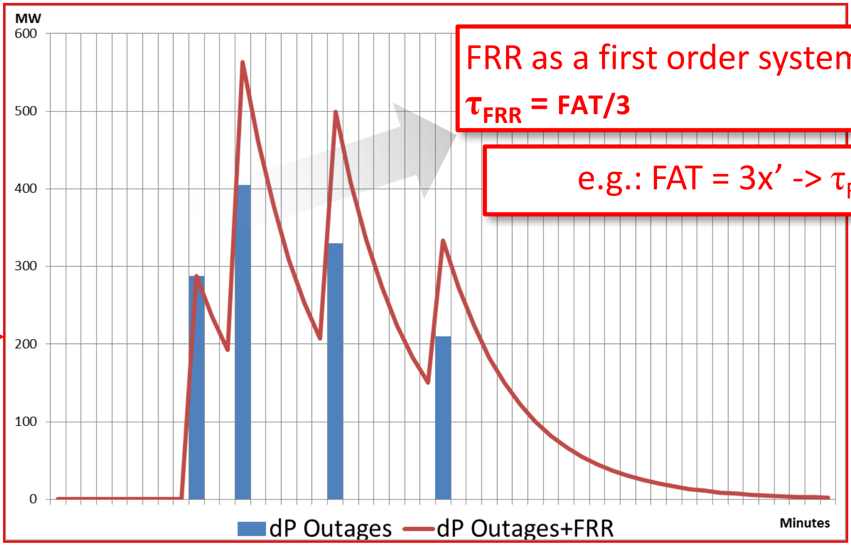
aFRR activation is simulated in response to dP. Its effect is considered reducing the power imbalance of $e^{-t/FRRtau}$ each minute

$\Delta P_{out+FRR}$



FRR effects are taken into account only against dP due to outages.

FRR effects on dP due to LL and DFD are already implicitly considered in the df themselves



FRR as a first order system with:
τ_{FRR} = FAT/3

e.g.: FAT = 3x' -> τ_{FRR} = x'

Outages of Generation Unit – List of units

The list of the Generation Unit to be considered is derived from ENTSO-E Transparency Platform.

It is used the «Production and Generation Units» table (with 2020 as reference year).

entsoe
Transparency Platform

Filter applied to data:

- **Generation Unit Status** = "Commissioned"
- **GU Installed Capacity** ≥ 100 MW

The total number of Generation Unit considered is:

- **191** for the Nordic Synchronous Area
- **1245** for the Continental Europe Synchronous Area

Outages of Generation Unit – Failure rate

An outage on a Generation Unit is a sudden loss of production leading to a power imbalance on the synchronous area.

To each Generation Unit shall be then associated:

- The probability of the event (yearly average number of occurrence)
- The power loss if the event occurs

The yearly number of occurrence of the event is derived from literature data.

The values are associated to different technologies.

Literature sources:

- Thermoelectrical Unit — VGB official Publication: "Analysis of Unavailability of Power Plants 2008 – 2017"
- Hydroelectrical Unit — Source still to be defined.
- Renewables Unit — Solar and Wind units failure rate is neglected

Outages of Generation Unit – Failure rate

Thermoelectrical Unit

The **«Analysis of Unaivalability of Power Plants 2008 – 2017»** VGB report has been analyzed. These are the main results in terms of yearly failure rate:

	Fossil-fired			Combined Cycle	Gas Turbine	Nuclear	Hydro
	Hard coal	Lignite	Gas/oil				
Average failure rate [n°events/unit/year]*	7.92			6.62	0.88	1.2	
Number of surveyed units	181			53	42	20	
Surveyed years	2008-2017						

Hydro data still missing

Load rejection/fast shutdown events with total loss of power.

Hydroelectrical Unit

VGB does not provide information oh Hydro

A possible wide and reliable data source could be the **GADS (Generating Availability Data System)**. It is a database collected by the **NERC (North American Electric Reliability Corporation)**.

The specific data that we needs are unfortunately not public. Together with ENTSO-E we contacted NERC for having/purchasing the data.

For clients outside USA the request needs to be officially approved by NERC management.

Possible back-up solution: to use the failure rate of thermal units

Renewables Unit

The failure rate of these Generation Units is neglected thanks to the typical distributed plants' organization.

The consequences on frequency of their failure are considered as error in the forecasts.

Partial Outages

The previous outages are "full events" (after them the power **output** is zero). For some technologies (e.g. Nuclear, Coal, etc.) partial outage are also very likely.

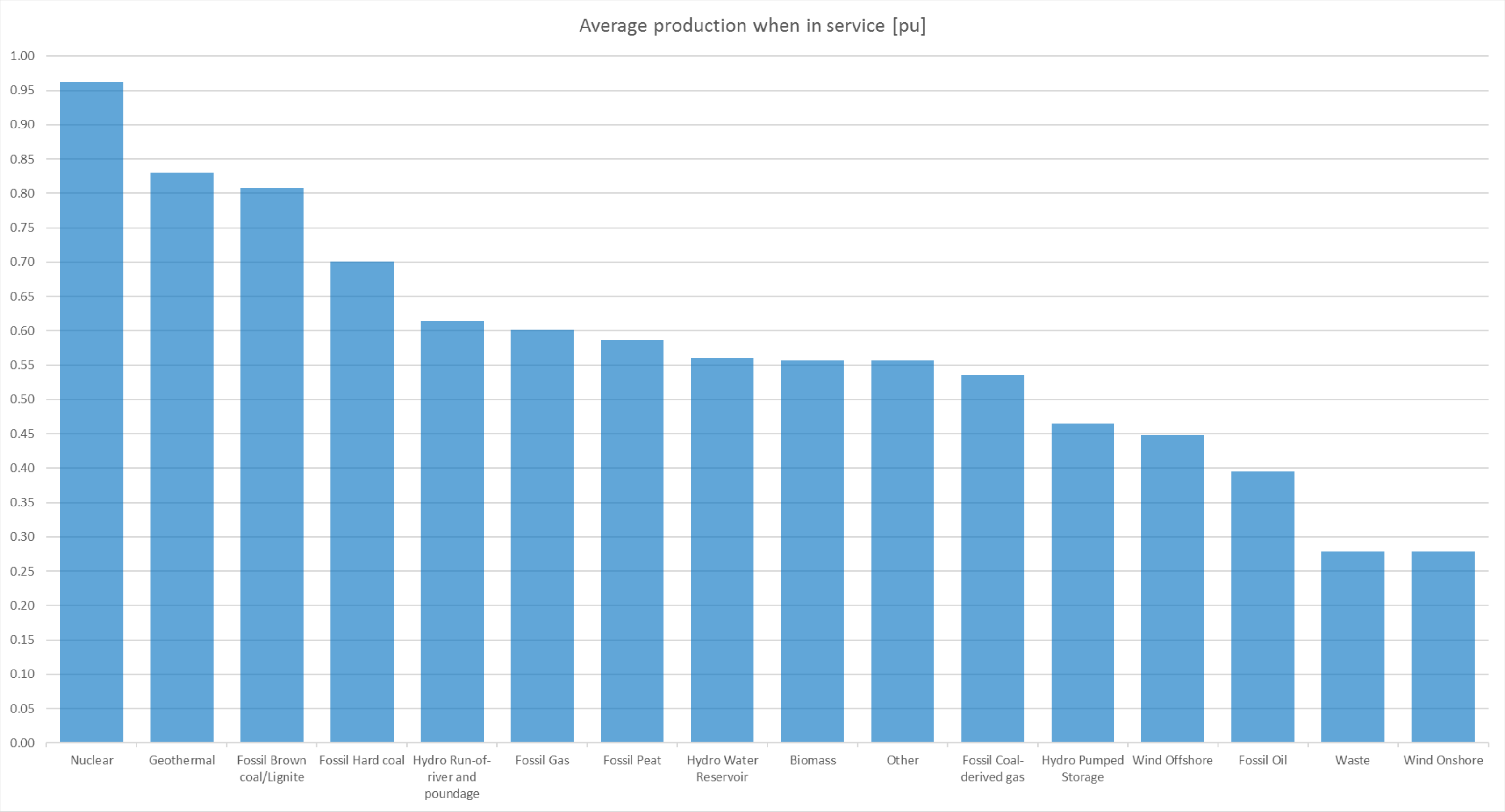
For these technologies also the statistics of partial outages will be considered (failure rate & typical power loss). These statistics will be derived from ENTSO-E Transparency platform.

Outages of Generation Unit – Generation Loss

When the Monte Carlo model randomly picks an outage (on the basis of its failure rate) also the power lost is needed. The power loss is equal to the power imbalance affecting the frequency deviation.

The actual power loss was the power produced at the moment of the outage.

Since in the simulation the <u>actual productions are not modeled</u>, the power loss has to be assumed.



The data come from ENTSO-E Transparency Platform ("Actual Generation Output Per Unit" tables).

The average production is calculated for each technology as the average output [pu] of each Generation Unit belonging the specific production type.

The average output of the single Generation Unit is the average production when the Unit **<u>is in service</u>** (the hours with P = 0 MW are not considered in the calculation).

Outages of Generation Unit – Generation Loss

Synchronous	GU InstalledCap	Country c	Country Na	ProductionType	Power Loss (RedFact)	Failure rate [event/
Nordic	110	NO	Norway	Hydro Water Reservoir	61.7	3.06
Nordic	136	NO	Norway	Hydro Water Reservoir	76.2	3.06
Nordic	100	NO	Norway	Hydro Water Reservoir	56.1	3.06
Nordic	100	NO	Norway	Hydro Water Reservoir	56.1	3.06
Nordic	220	NO	Norway	Hydro Water Reservoir	123.3	3.06
Nordic	102	NO	Norway	Hydro Water Reservoir	57.2	3.06
Nordic	102	NO	Norway	Hydro Water Reservoir	57.2	3.06
Nordic	104	NO	Norway	Hydro Water Reservoir	58.3	3.06
Nordic	120	NO	Norway	Hydro Water Reservoir	67.3	3.06
Nordic	120	NO	Norway	Hydro Water Reservoir	67.3	3.06
Nordic	175	NO	Norway	Hydro Water Reservoir	98.1	3.06
Nordic	110	NO	Norway	Hydro Water Reservoir	61.7	3.06
Nordic	110	NO	Norway	Hydro Water Reservoir	61.7	3.06
Nordic	103	NO	Norway	Hydro Water Reservoir	57.7	3.06
Nordic	103	NO	Norway	Hydro Water Reservoir	57.7	3.06
Nordic	103	NO	Norway	Hydro Water Reservoir	57.7	3.06
Nordic	108	NO	Norway	Hydro Water Reservoir	60.5	3.06
Nordic	100	NO	Norway	Hydro Run-of-river and poundag	61.4	3.06
Nordic	105	NO	Norway	Hydro Run-of-river and poundag	64.5	3.06
CE	340	CH	Switzerland	Hydro Water Reservoir	190.6	3.06
CE	421	CH	Switzerland	Hydro Water Reservoir	236.0	3.06
CE	108	CH	Switzerland	Hydro Water Reservoir	60.5	3.06
CE	123	CH	Switzerland	Hydro Water Reservoir	68.9	3.06
CE	140	CH	Switzerland	Hydro Water Reservoir	78.5	3.06
CE	176	CH	Switzerland	Hydro Water Reservoir	98.7	3.06
CE	1020	CH	Switzerland	Nuclear	981.2	1.2
CE	190	CH	Switzerland	Hydro Water Reservoir	106.5	3.06
CE	230	CH	Switzerland	Hydro Water Reservoir	128.9	3.06
CE	288	CH	Switzerland	Hydro Water Reservoir	161.4	3.06
CE	384	CH	Switzerland	Hydro Water Reservoir	215.2	3.06
CE	1254	CH	Switzerland	Hydro Water Reservoir	702.9	3.06
CE	137	IT	Italy	Hydro Pumped Storage	63.7	3.06
CE	130	IT	Italy	Hydro Run-of-river and poundag	79.9	3.06
CE	166	IT	Italy	Hydro Run-of-river and poundag	102.0	3.06
CE	391	IT	Italy	Fossil Gas	235.0	7.92
CE	164	IT	Italy	Hydro Run-of-river and poundag	100.8	3.06

Assumption: power loss equal to the installed power multiplied for the reduction factor calculated from ENTSO-E Transparency Platform.

The reduction factor depends on the generation unit technology. The values are:

Technology	Reduction Factor
Hydro Run-of-river and poundage	0.61
Hydro Water Reservoir	0.56
Fossil Gas	0.60
Wind Onshore	0.28
Hydro Pumped Storage	0.46
Nuclear	0.96
Wind Offshore	0.45
Geothermal	0.83
Fossil Hard coal	0.70
Fossil Brown coal/Lignite	0.81
Solar	0.00
Biomass	0.56
Fossil Oil	0.40
Other	0.56
Waste	0.28
Fossil Coal-derived gas	0.54
Fossil Peat	0.59

e.g. : A Hydro Water Reservoir Generation Unit having 300 MW installed power cause a loss of production equal to 168 MW when an outage occurs on it.

Outages of HVDC – List on connections

The HVDC connections that can affect the frequency on the Nordic and CE are those which have at least one end connected the these synchronous areas.

Unit	SA 1	SA 2	Installed Power [MW]	Power Loss [MW]
Interconn. France Angleterre	CE	GB	2000	1000
BritNed	CE	GB	1000	500
NorNed	CE	Nordic	700	350
Skagerrak 1_2	CE	Nordic	500	250
Skagerrak 3	CE	Nordic	300	150
Skagerrak 4	CE	Nordic	700	350
Konti-Skan 1	CE	Nordic	370 (340 Nordic export)	185 (170)
Konti-Skan 2	CE	Nordic	370 (340 Nordic export)	185 (170)
StoreBaelt	CE	Nordic	600	300
Kontek	CE	Nordic	600	300
Baltic Cable	CE	Nordic	600	300
SwePol	CE	Nordic	600	300
NordBalt	Nordic	Baltic/Russia	700	350
Estlink	Nordic	Baltic/Russia	350	175
Estlink 2	Nordic	Baltic/Russia	650	175
LitPol	CE	Baltic/Russia	500	250
Nemo	CE	GB	1000	500
Vyborg	CE	Baltic/Russia	1000 (350 Russia import)	250 (175)

List on HVDC in which at least one end belongs to C.E. or Nordic S.A.

Outages of HVDC – Failure Rates

The failure rate of HVDC are derived from data on ENTSO-E Transparency Platform:

Source Table

Unavailability in Transmission Grid

Planned Unavailability in the Transmission Grid [10.1.A]
Changes in Actual Availability in the Transmission Grid [10.1.B]

Filter applied to data:

- **AreaTypeCode** = "CTA"
- **Status** = "Active"
- **Type** = "Forced"
- **Production Type** = "DC Link"
- **MRID univocal**

12/2014 → 06/2019

55 months of observation

Results:

Unit	Observed months	Yearly avg failure rate [event/year]
Interconn. France Angleterre	55	15.3
BritNed	55	13.4
NorNed	55	0.0
Skagerrak 1_2	55	5.4
Skagerrak 3	55	0.0
Skagerrak 4	53	0.0
Konti-Skan 1	55	8.0
Konti-Skan 2	55	0.0
StoreBaelt	55	0.0
Kontek	55	8.3
Baltic Cable	55	3.9
SwePol	55	4.3
NordBalt	41	8.2
Estlink	55	4.6
Estlink 2	55	0.0
LitPol	42	1.0
Nemo	4	12.0
Vyborg	55	5.3

There are interconnections without any recorded outage.
For them the considered failure rate is equal to the average failure rate of the others:

Average HVDC Failure Rate = 7.47 event / year

Outages of HVDC – Power Loss

When there is an outage on a HVDC connection, the effect on frequency depends either on the power flow and on the direction.

- **Since in the simulation the actual flows are not modeled, the power loss has to be assumed.**

  The assumption is that the average power loss is equal to half the installed transmission capacity.

- **The flow is not considered equal in both the direction.**

  Starting from the ENTSO-E Transparency Platform data, the number of hours in which the HVDC is working in each direction is calculated.

  On the basis of these values the total failure rate is allocated on the two directions.

Example on interconnection France - Angleterre:

The flow is in the 89% of the hours from France to GB

The total failure rate from ENTSO-E TP is equal to 15.3 event/year

Two different kind of events are considered:

- Failure when France is exporting with failure rate equal to 15.3 * 0.89 = 13.7 event/year

  These events are loss of load for the CE

- Failure when France is importing with failure rate equal to 15.3 * 0.11 = 1.6 event/year

  These events are loss of generation for the CE

Outages of HVDC – Power Loss

	Equivalent HVDC to be assigned to CE		
	Connection Name	Power Loss	Failure Rate
CE Export	Interconnexion France Angleterre - CE Export	-1000	13.66
	BritNed - CE Export	-500	12.61
	NorNed - CE Export	-350	7.47
	Skagerrak 1_2 - CE Export	-250	1.78
	Skagerrak 3 - CE Export	-150	7.47
	Skagerrak 4 - CE Export	-350	7.47
	Konti-Skan 1 - CE Export	-185	4.61
	Konti-Skan 2 - CE Export	-185	7.47
	StoreBaelt - CE Export	-300	7.47
	Kontek - CE Export	-300	3.49
	Baltic Cable - CE Export	-300	1.76
	SwePol - CE Export	-300	0.45
	LitPol - CE Export	-250	0.38
	Nemo - CE Export	-500	11.20
CE Import	Interconnexion France Angleterre - CE Import	1000	1.61
	BritNed - CE Import	500	0.69
	NorNed - CE Import	350	7.47
	Skagerrak 1_2 - CE Import	250	4.09
	Skagerrak 3 - CE Import	150	7.47
	Skagerrak 4 - CE Import	350	7.47
	Konti-Skan 1 - CE Import	170	3.32
	Konti-Skan 2 - CE Import	170	7.47
	StoreBaelt - CE Import	300	7.47
	Kontek - CE Import	300	4.97
	Baltic Cable - CE Import	300	2.16
	SwePol - CE Import	300	3.18
	LitPol - CE Import	250	0.64
	Nemo - CE Import	500	0.42

	Equivalent HVDC to be assigned to Nordic		
	Connection Name	Power Loss	Failure Rate
Nordic Export	NorNed - Nordic Export	-350	7.47
	Skagerrak 1_2 - Nordic Export	-250	4.09
	Skagerrak 3 - Nordic Export	-150	7.47
	Skagerrak 4 - Nordic Export	-350	7.47
	Konti-Skan 1 - Nordic Export	-170	3.32
	Konti-Skan 2 - Nordic Export	-170	7.47
	StoreBaelt - Nordic Export	-300	7.47
	Kontek - Nordic Export	-300	4.97
	Baltic Cable - Nordic Export	-300	2.16
	SwePol - Nordic Export	-300	3.18
	NordBalt - Nordic Export	-350	6.35
	Estlink - Nordic Export	-175	3.54
	Estlink 2 - Nordic Export	-325	7.47
	Vyborg - Nordic Export	-175	0.06
Nordic Import	NorNed - Nordic Import	350	7.47
	Skagerrak 1_2 - Nordic Import	250	1.78
	Skagerrak 3 - Nordic Import	150	7.47
	Skagerrak 4 - Nordic Import	350	7.47
	Konti-Skan 1 - Nordic Import	185	4.61
	Konti-Skan 2 - Nordic Import	185	7.47
	StoreBaelt - Nordic Import	300	7.47
	Kontek - Nordic Import	300	3.49
	Baltic Cable - Nordic Import	300	1.76
	SwePol - Nordic Import	300	0.45
	NordBalt - Nordic Import	350	0.98
	Estlink - Nordic Import	175	1.09
	Estlink 2 - Nordic Import	325	7.47
	Vyborg - Nordic Import	250	5.28

Vyborg max export towards Russia = 350 MW

Vyborg link is a back-to-back HVDC with four converter blocks. The considered average outage is 1/4 of installed power.

For each SA, each HVDC is considered twice: one for the import and the other for the export.

Outages related to loss of load

A further potential source of power imbalance is the loss of load due to critical busbar/substation fault.

This kind of outages are neglected due to their unlikelihood and limited effects.

The ENTSO-E official **«2017 Incident Classification Scale ANNUAL REPORT»** reports:

- **Continental Europe Synchronous Area:**
  “There were 374 incidents reported for transmission network elements (T0) in 2017, of which 6 cases (3 cases from Transelectrica) also involved load disconnections ranging from 15 to 198 MW (…)**”.** Pg.31

- **Nordic Synchronous Area:**
  “The majority of the incidents were classified as incidents on transmission network elements (T1) (…) two were incidents involving load (L1)”. Pg. 47

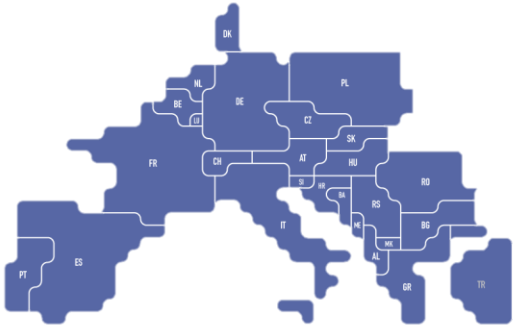
2. Historical frequency deviations

Data collection on actual frequency on both synchronous areas.

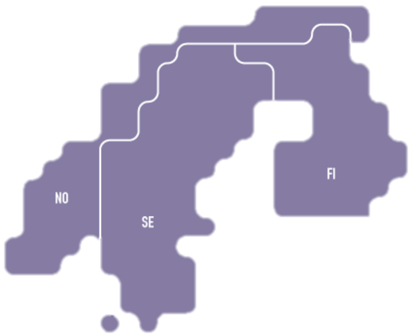
Frequency deviation analysis.

Historical frequency deviations
Data Collection

Continental Europe SA



Nordic SA

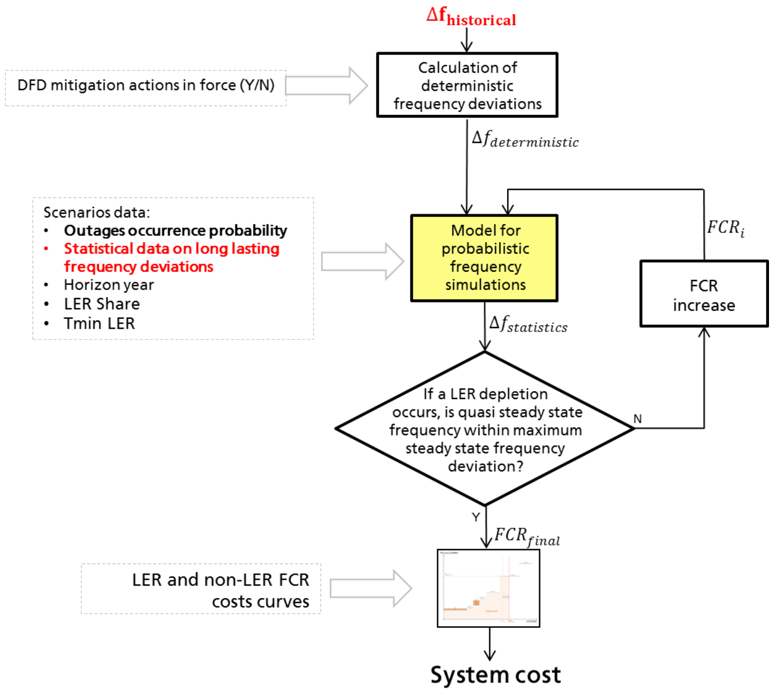


Note:

- Missing data or full-scale values → set to 50 Hz
- Frequency averaged to 1-minute time-step
- 2004-2007 dataset under investigation

Frequency timeframe

2004 - 2018



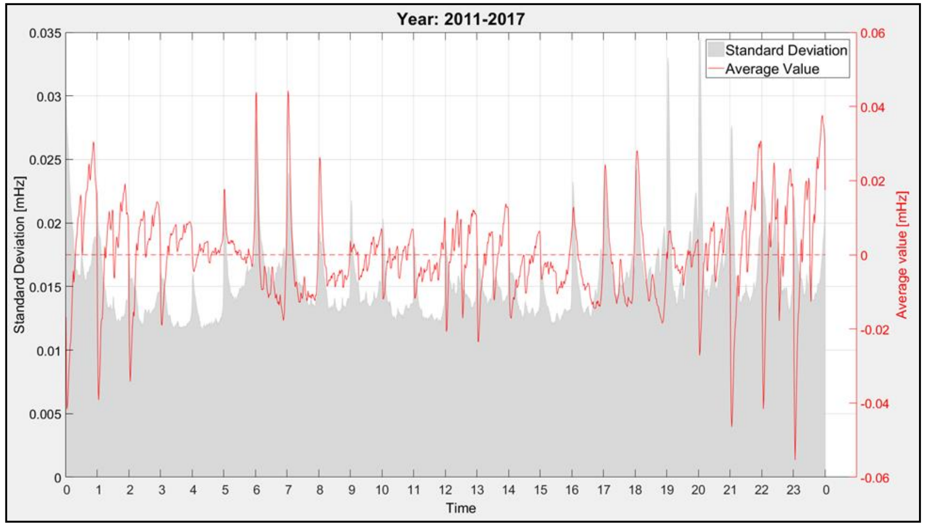
Historical frequency is used to calculate **statistics** about **Deterministic Frequency Deviations** and **Long Lasting events** → not the entire historical frequency set is applied along the years, but **only Deterministic Frequency Deviations and Long Lasting events extracted by the model**

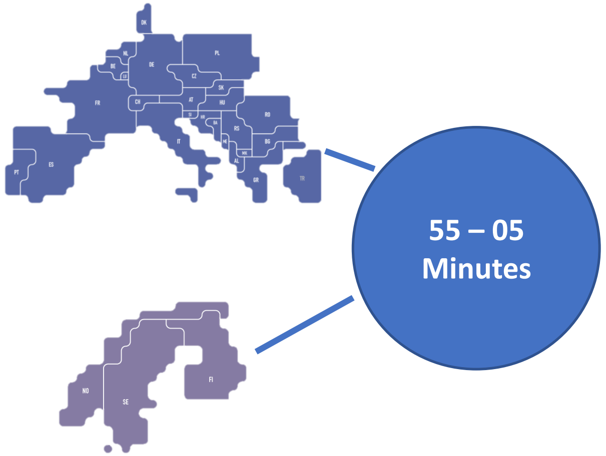
Historical frequency deviations
Deterministic frequency deviations

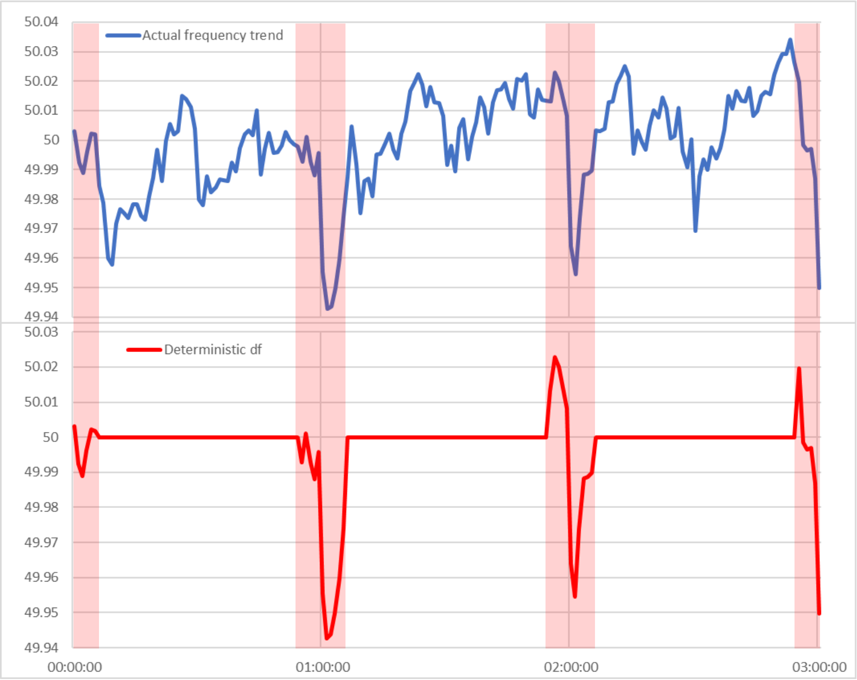
CBA Methodology – Deterministic frequency deviations

- Market induced effects due to the power difference between continuous ramping of load and discontinuous/stepwise ramping of generation according to the scheduling resulted from the market

2011-2017 CE Daily frequency deviation





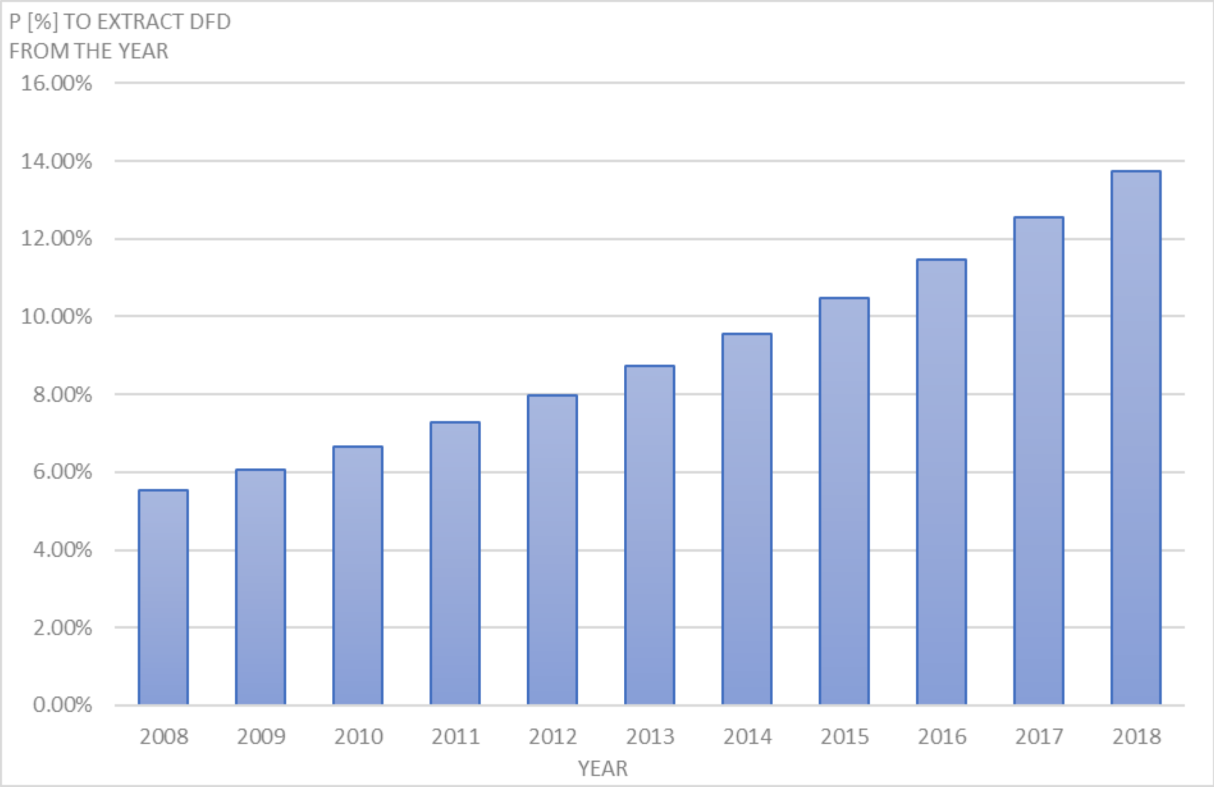


The frequency trend between 55th minute and 5th minute (included) of each hour in the entire frequency dataset is collected, together with the hour of occurrence

Historical frequency deviations
Deterministic frequency deviations

For each simulated day, the Monte Carlo model randomly choses the DFD trends that occurred in the same calendar day in one of the past years.

The choice exploits an exponential function in order to consider as more likely the most recent years.



$$p_y = \frac{1}{N_{years}} e^{-\frac{y - y\_current}{N_{years}}}$$

$y\_current$ Year in which the simulation is run (e.g. 2019)

N_{years} Number of collected years (e.g. 2008-2019 ->11)

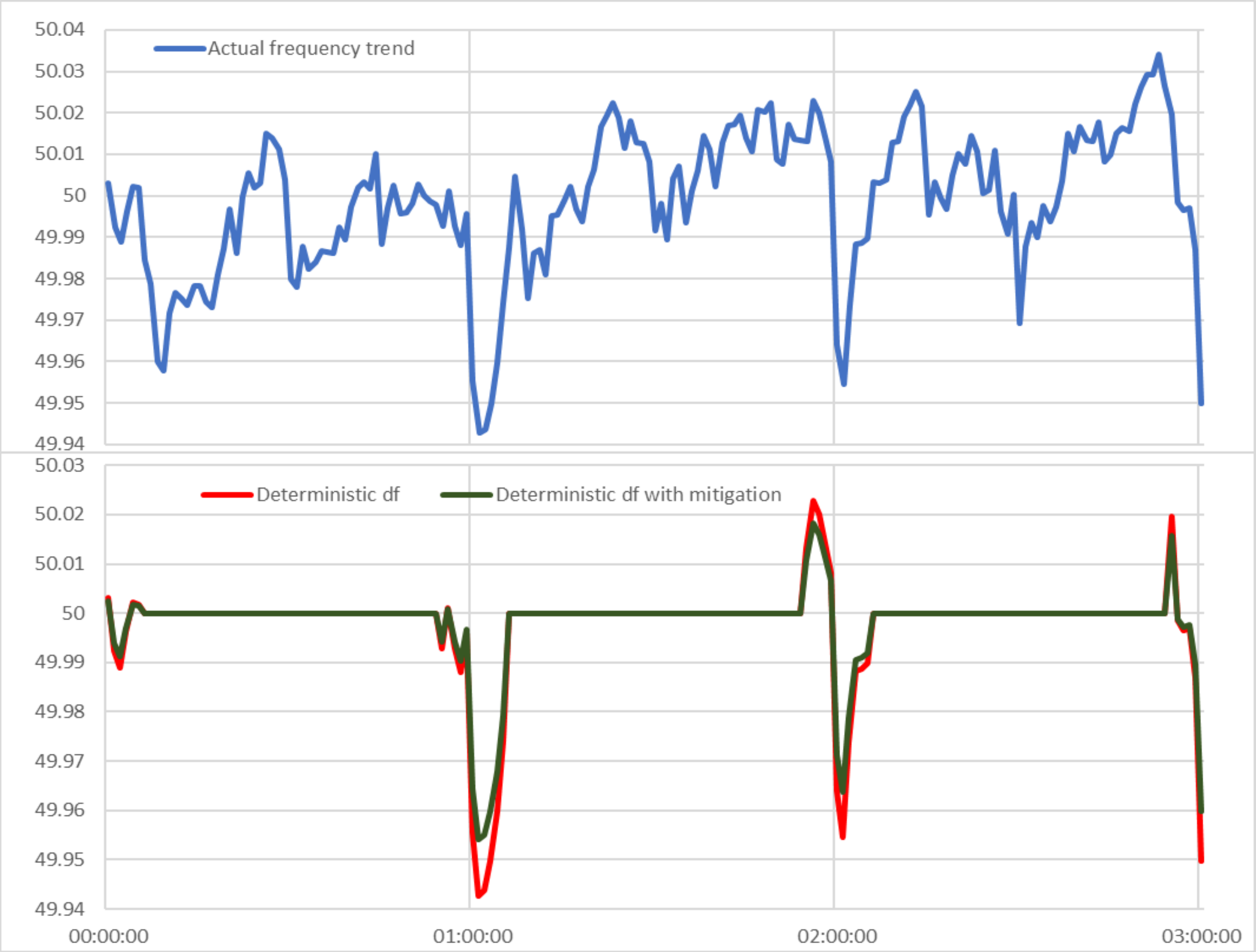
p_y Probability that Monte Carlo extracts a DFD occurred in the year y

Historical frequency deviations
Deterministic frequency deviations - Mitigation

In the model are taken into account the possible mitigation actions that could be developed in both S.A. according to Art. 138.

In the simulation with the mitigation actions in force, the DFD are reduced by a parametrical factor equal to **0.8**.

It is chosen as a realistic short-term factor since the target scenario for the CBA is 2020. If significant changes → methodology foresees the re-run of the CBA

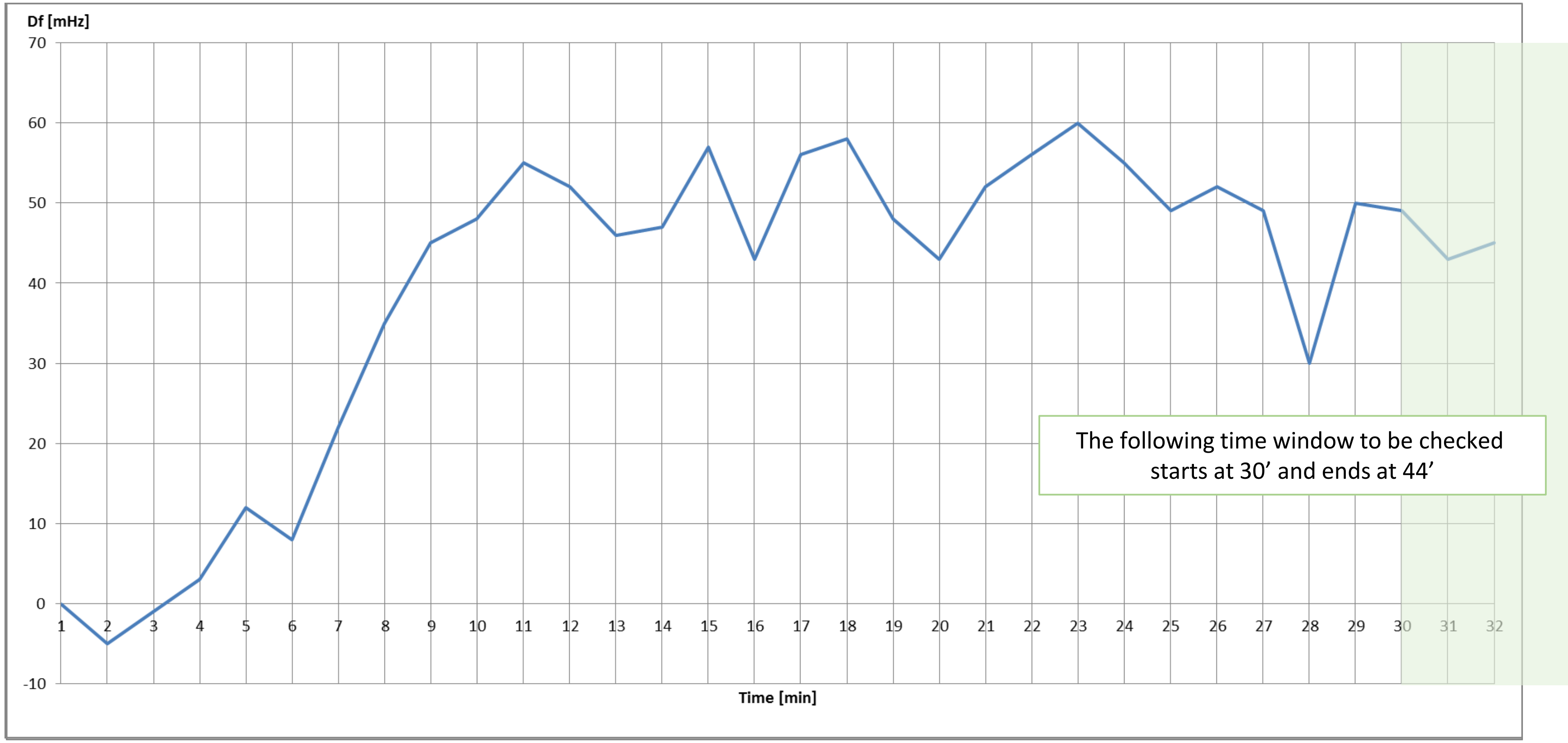


Historical frequency deviations
Long lasting frequency deviations

CBA Methodology – Long lasting definition

- Long lasting frequency deviation is an event with an average steady state frequency deviation larger than the standard frequency deviation over a period longer than the time to restore frequency.

CE Illustrative example



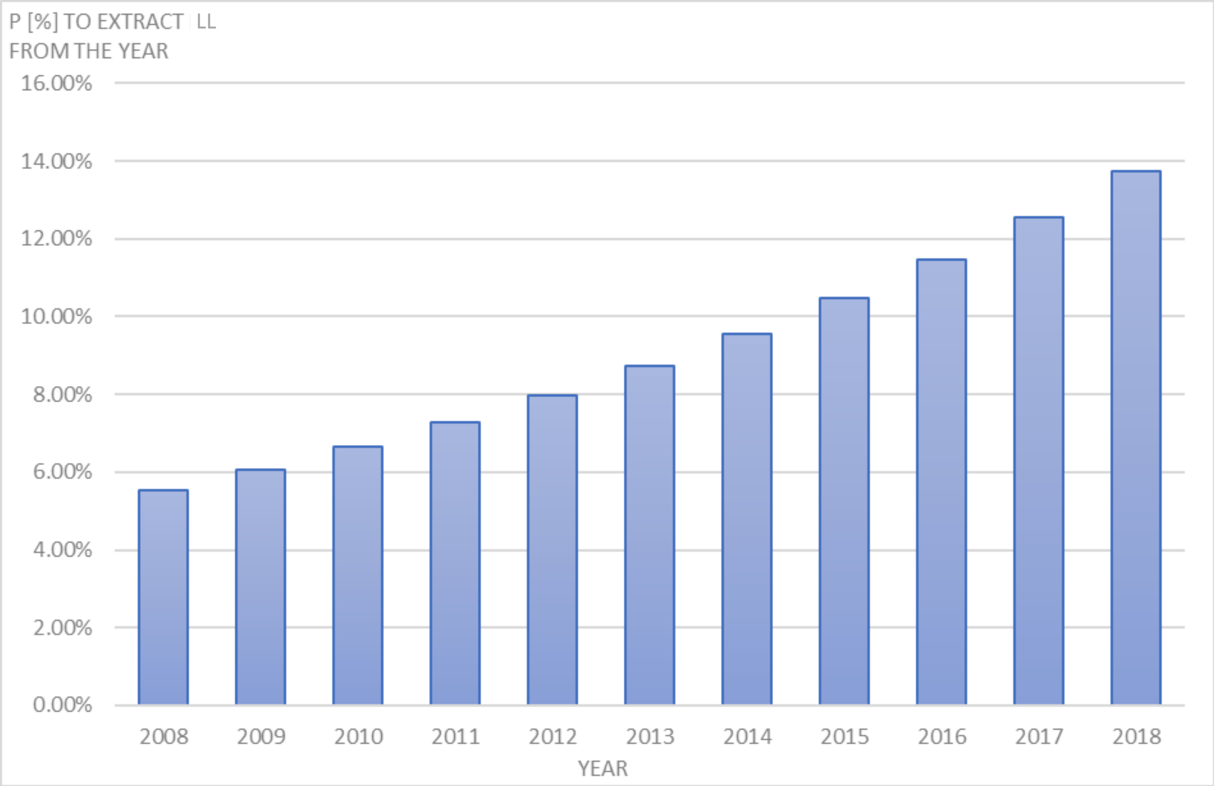
For each long lasting event are collected:

- Frequency trend
- Date and time of long lasting

Historical frequency deviations
Long lasting frequency deviations

For each minute of the day, the Monte Carlo model randomly choses the LL trends that occurred in the same minute of the day in one of the past years.

The choice exploits an exponential function in order to consider as more likely the most recent years.



$$p_y = \frac{1}{N_{years}} e^{-\frac{y - y\_current}{N_{years}}}$$

$y\_current$	Year in which the simulation is run (e.g. 2019)
N_{years}	Number of collected years (e.g. 2008-2019 ->11)
p_y	Probability that Monte Carlo extracts a LL occurred in the year y

3. Most relevant frequency events

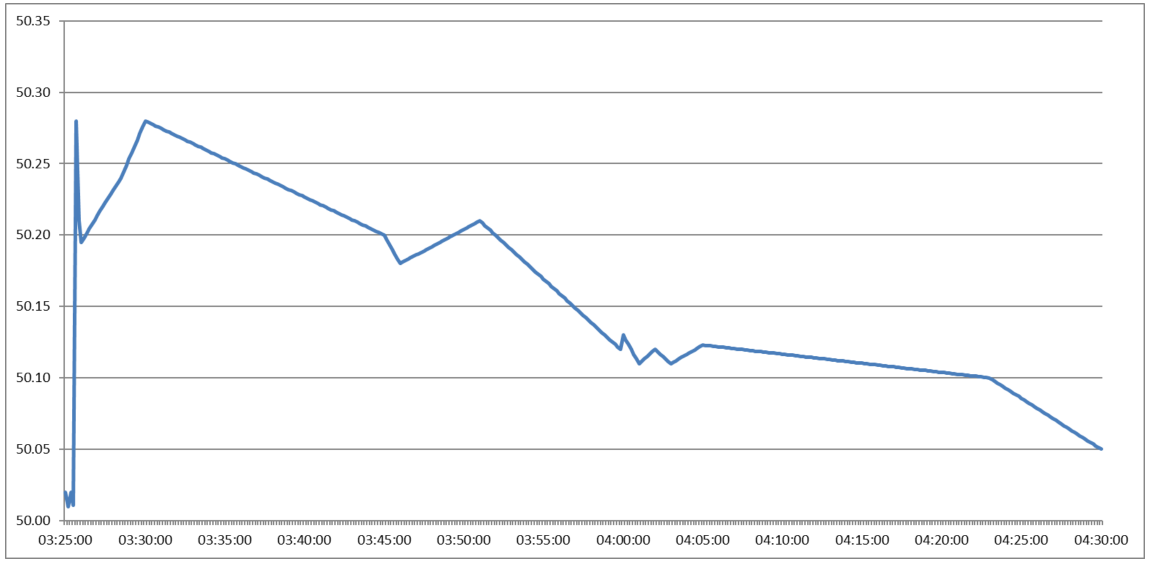
Definition and data collection of the actual events to be considered as most relevant.

Most relevant frequency events Continental Europe SA

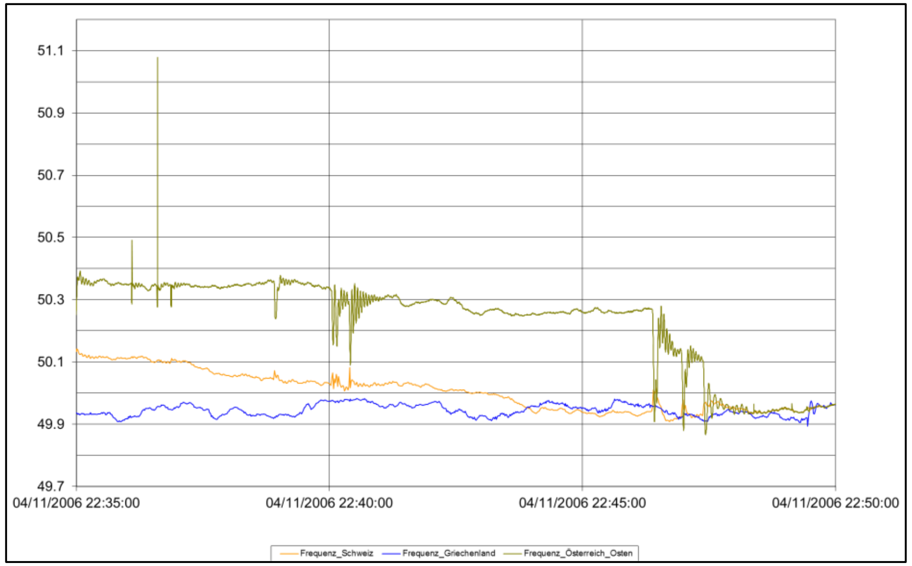
The most relevant frequency events that will be taken into account for the CE SA are the following:

- **28/09/2003 Italian blackout;**
- **04/11/2006 CE system split event**

2003 Italian blackout trend (overfrequency on the CE system)



04/11/2006 CE system split event



The most relevant events are not within the inputs extracted in the Monte Carlo analysis, but will be used to check the different timeframe and LER share in terms of system stability*

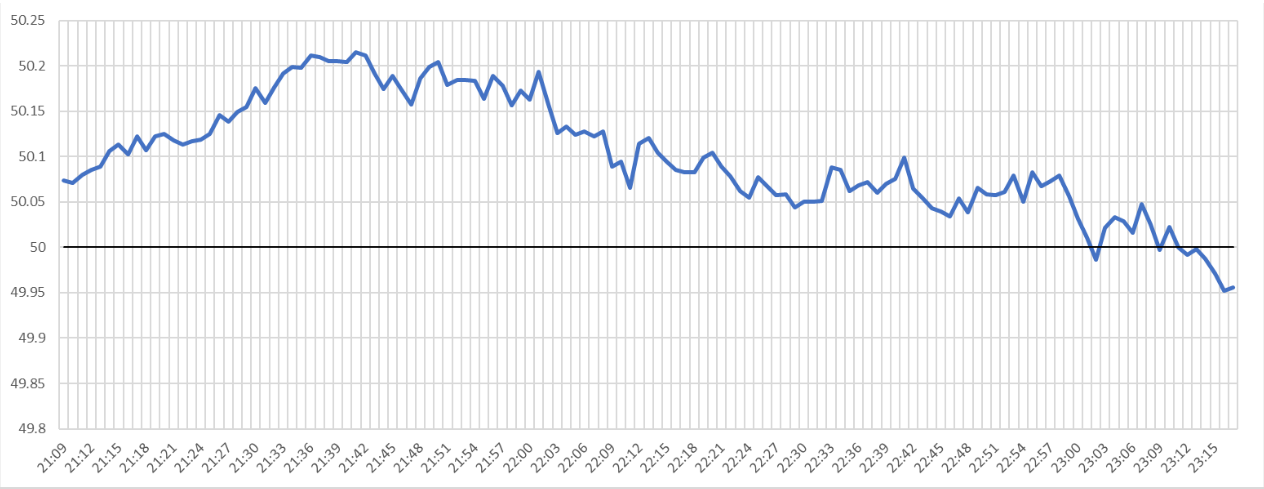
*see Section 5.8 of Explanatory document of the CBA methodology for further information

Most relevant frequency events Nordic SA

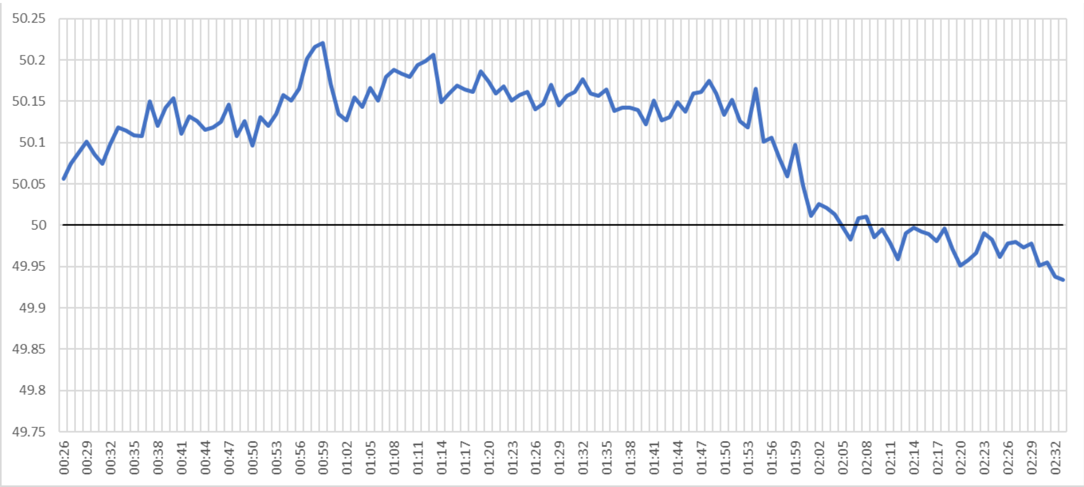
The most relevant frequency events that will be taken into account for the Nordic SA are selected based on duration and amplitude of frequency deviations, and are the following:

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

03/10/2011



09/05/2018



The most relevant events are not within the inputs extracted in the Monte Carlo analysis, but will be used to check the different timeframe and LER share in terms of system stability*

*see Section 5.8 of Explanatory document of the CBA methodology for further information

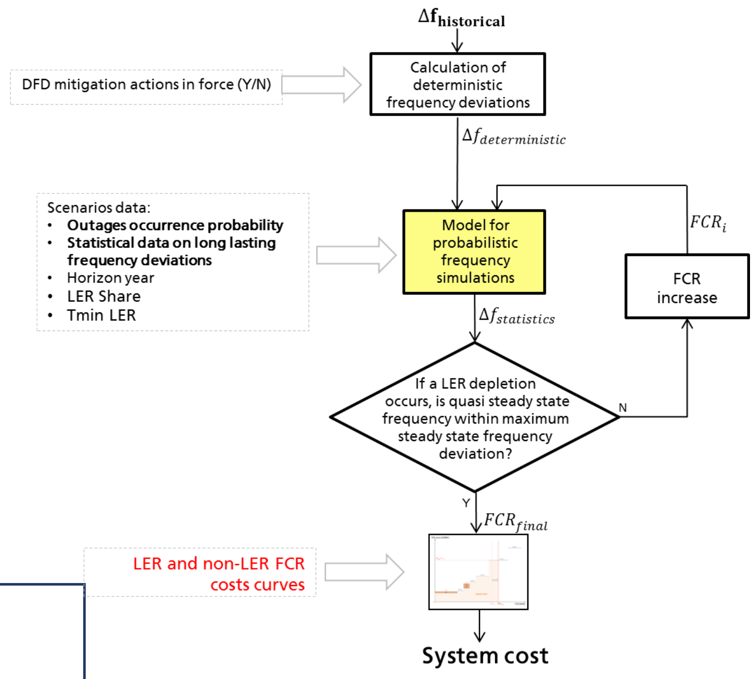
4. Cost of LER & non-LER

Data collection methodology and results

LER and non-LER costs data collection and analysis – general assumptions

<u>2020 is the reference year</u> both for LER and non-LER resources

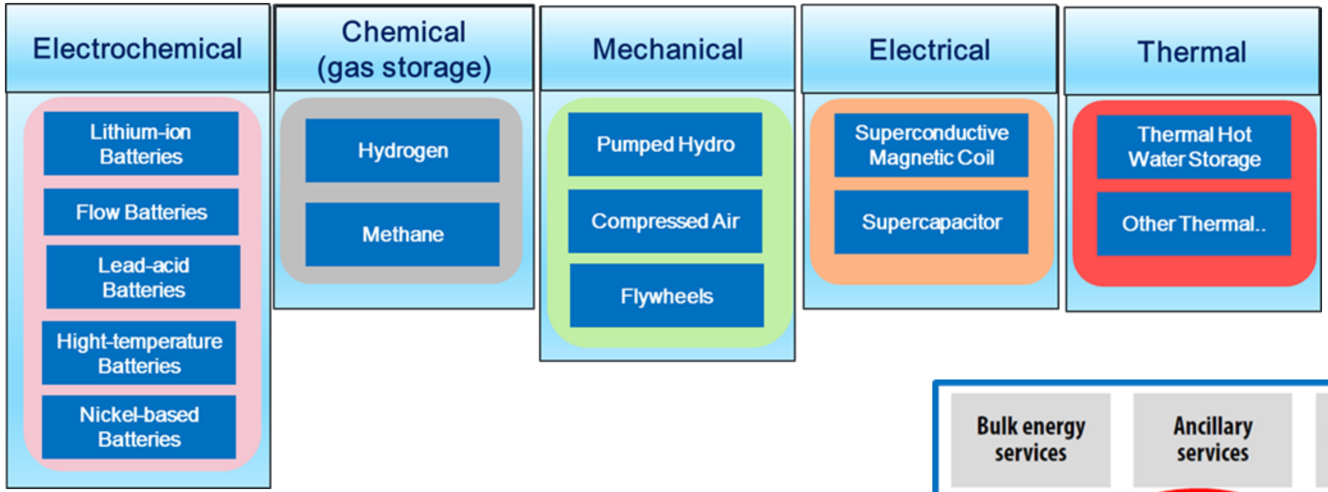
- 2020 is the investment year (and the commissioning year) for new LER specifically commissioned for FCR provision
- All the scenario data used in the data collection and analysis refer to year 2020
- The supply curves resulting from the data collection and analysis activities refer to year 2020



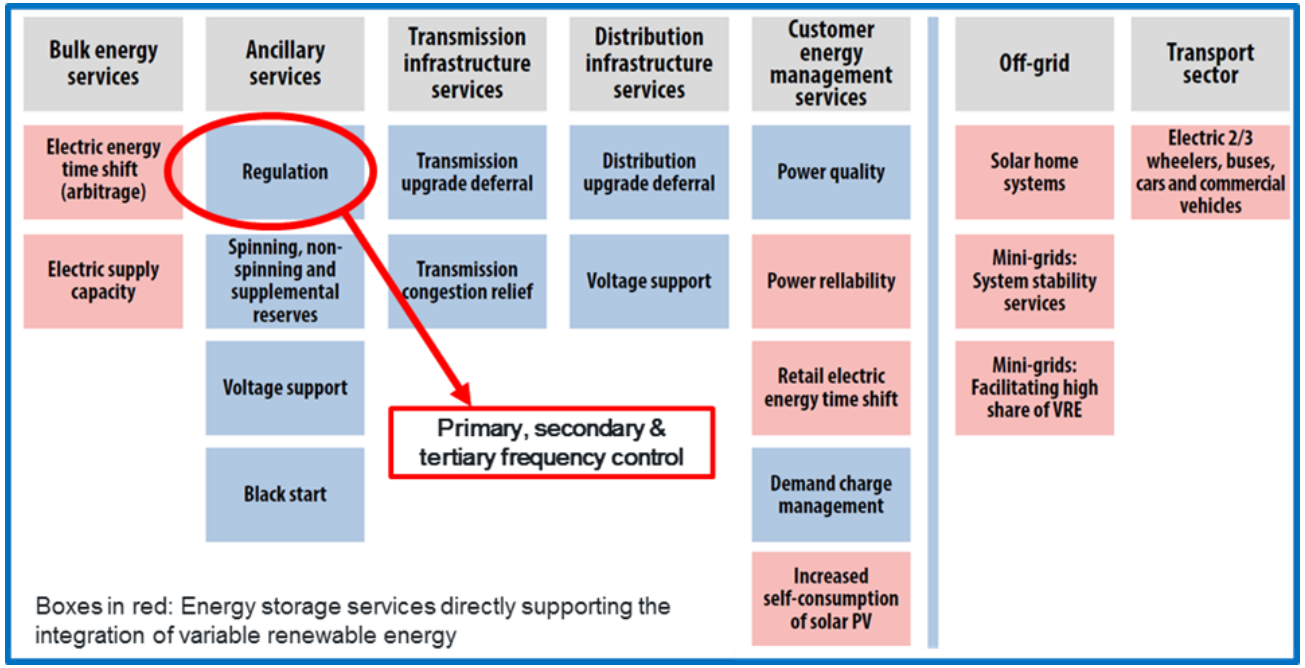
<u>All costs/prices are expressed in real terms in €2019</u>

<u>ECB</u> yearly average exchange rates and **<u>IMF</u>** inflation rates have been used

LER for FCR provision: available technologies and possible services

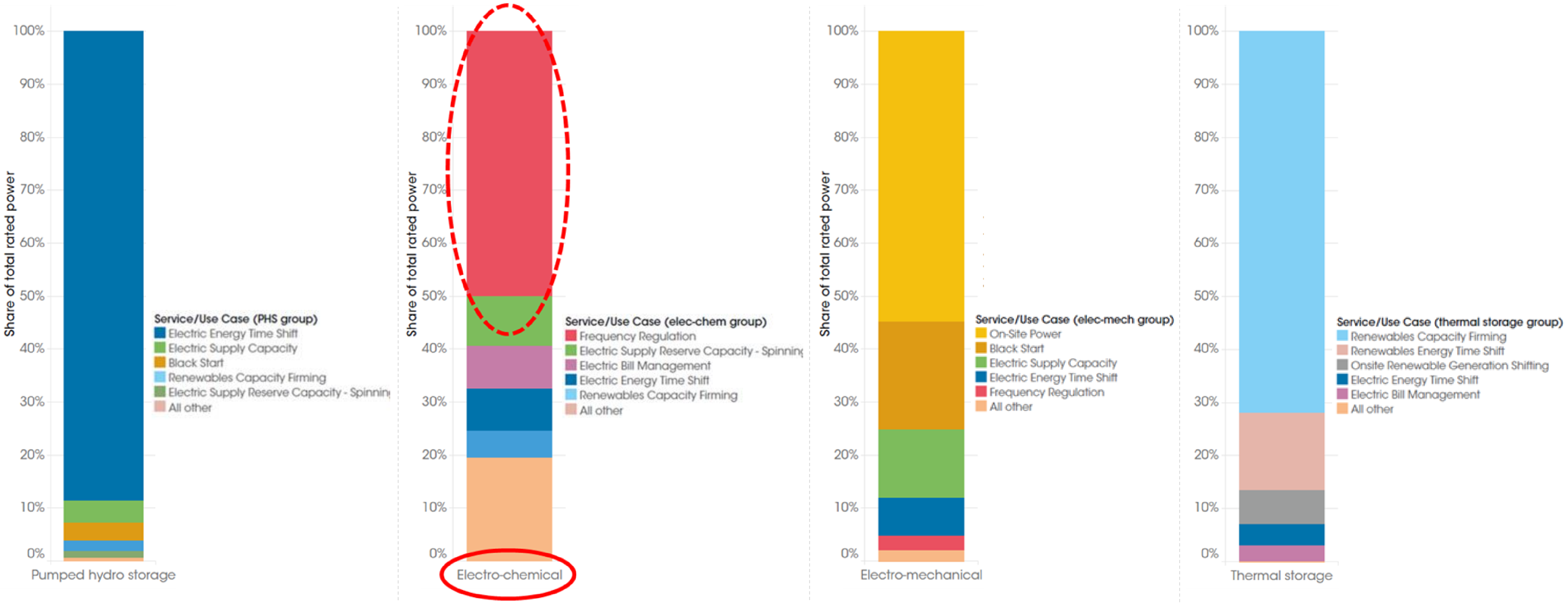


Main Electricity Storage Systems classification. Source: IRENA, Electricity storage and renewables: Costs and markets to 2030, October 2017 and EASE website.



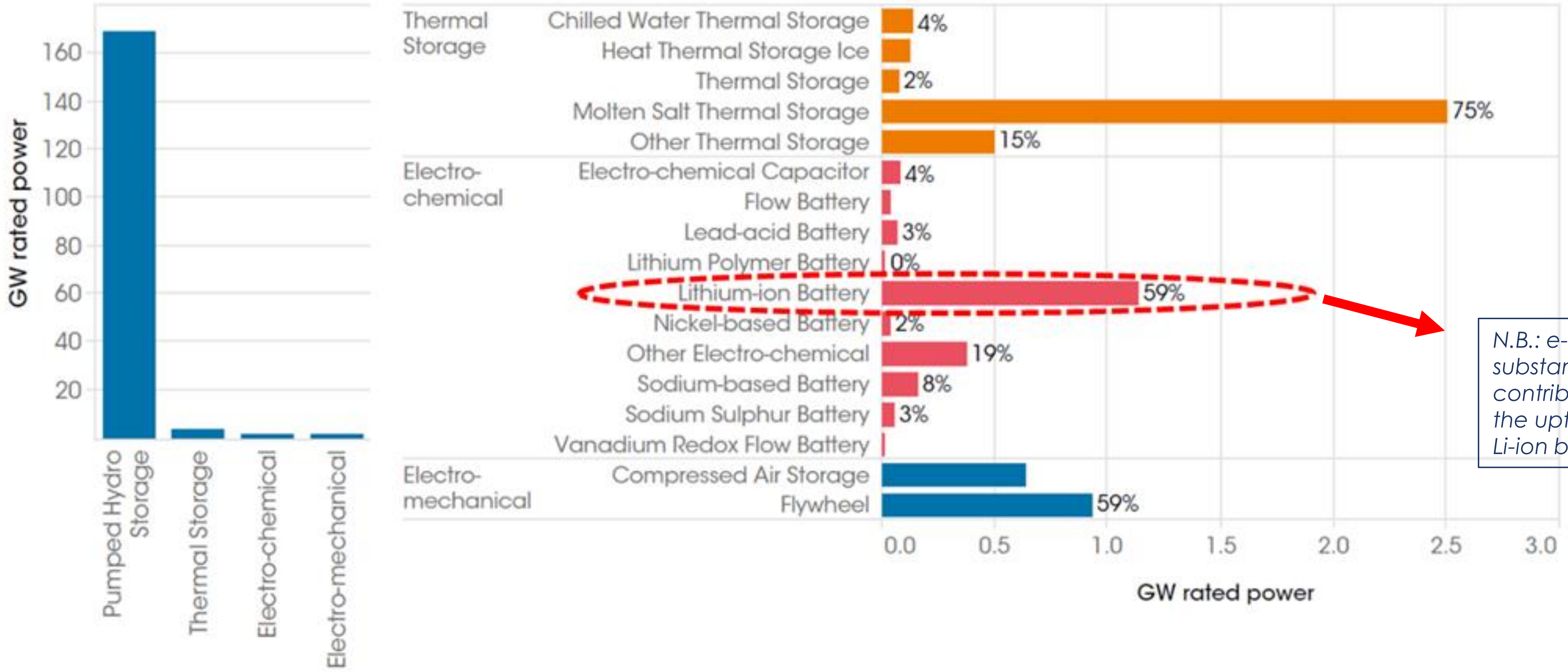
Range of services that can be provided by electricity storage. Source: IRENA, Electricity storage and renewables: Costs and markets to 2030, October 2017.

LER for FCR provision: services per technology



Global operational electricity storage capacity shares by service/use case and ESS group as at mid-2017. Source: IRENA, Electricity storage and renewables: Costs and markets to 2030, October 2017.

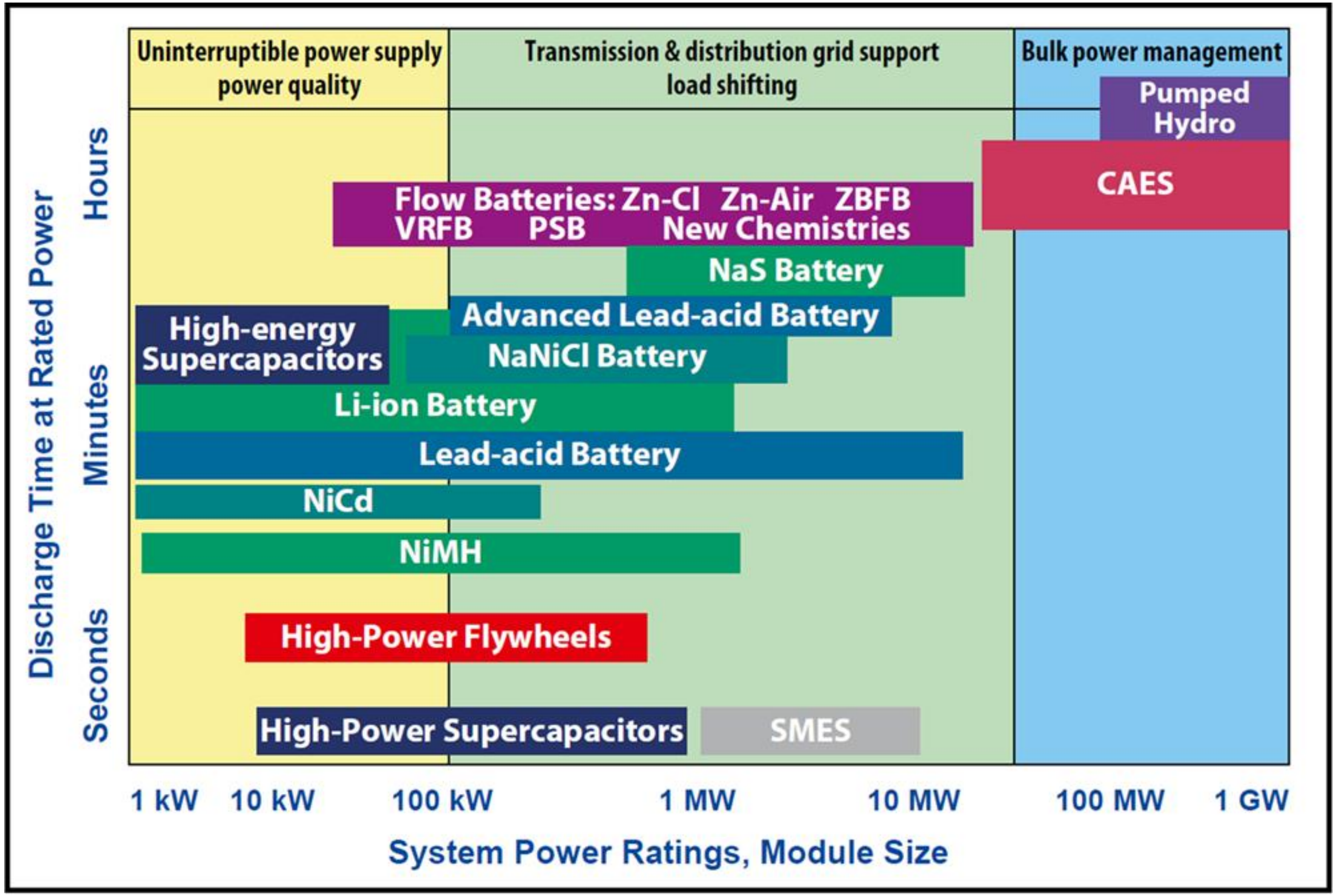
LER for FCR provision: most common technologies



N.B.: e-mobility substantially contributed to the uptake of Li-ion batteries

Global operational electricity storage capacity by technology as at mid-2017.
Source: IRENA, Electricity storage and renewables: Costs and markets to 2030, October 2017.

LER for FCR provision: duration (time period) per technology



Positioning of some electricity storage technologies according to their power rating, discharge times at rated power and their main application.
Source: IRENA, Electricity storage and renewables: Costs and markets to 2030, October 2017.

LER for FCR provision: other sources pointing to Li-ion batteries

European Association for Storage of Energy (EASE)

- Li-ion batteries for frequency regulation applications

Terna's pilot project on "Energy Intensive" and "Power Intensive" storage

- 5 Li-ion (0.5 /1 h duration) for the "Power Intensive" Storage Test Labs

Lazard's 2018 levelized cost of storage analysis

- Focus only on commercially available technologies – only Li-ion for all use cases

US DoE Global Energy Storage Database

- 1600 projects, 60% electrochemical systems, 40% Li-ion

Further crucial element: actual data availability
→ Sufficiently **detailed costs data** (differentiated according to the **duration**)

LER for FCR provision: three categories

1. New LER* dedicated to FCR provision

2. New LER* non specifically commissioned for FCR provision

3. Existing LER

** New LER are considered in the model only in the simulations where the LER share exceeds the current existing LER amount.*

1 New LER dedicated to FCR provision – main data sources

- IRENA - "Electricity Storage and Renewables: Costs and Markets to 2030" (October 2017)
- LAZARD – "Levelised Cost of Storage Analysis – Version 4.0" (November 2018)
- U.S. Energy Information Administration – "U.S. Battery Storage Market Trends" – (May 2018)
- U.S. Department of Energy - Global Energy Storage Database - https://energystorageexchange.org/
- Energy & Strategy Group (Polytechnic University of Milan) – "Renewable Energy Report" – (May 2019)
- The European Association for Storage of Energy (EASE)
- IEA – "World Energy Investment 2019" (May 2019)
- Terna energy storage pilot projects documents
- Rocky Mountain Institute "The Economics of Battery Energy Storage" (October 2015).
- The US Energy Storage Association (ESA)
- The Institute of the Economics of Energy Sources (IEFE), Bocconi University
- National Renewable Energy Laboratory (NREL)
- ElectraNet's ESCRI-SA Battery Energy Storage System
- Press releases and other documents from different stakeholders on specific project
- Academic literature for specific aspects (battery degradation)

1 New LER dedicated to FCR provision – main variables

LER costs (CAPEX - €/MW) can vary according to:

Technologies, size and year to be set according to the available literature and data

- ✓ the specific technology considered
- ✓ the size (MW of installed power)
- ✓ the investment year
- ✓ the LER duration (Energy to Power – E/P – ratio)

Bigger systems have lower cost per unit of installed capacity - €/MW (ceteris paribus)

The costs of certain technologies, like batteries, decreased substantially in the last few years and are expected to keep on decreasing in the future

Higher E/P ratio → higher €/MW unit costs

The LER durations of interests are already known

The cost analysis has been conducted considering four durations:

15 minutes	20 minutes	25 minutes	30 minutes
30 minutes (E/P = 0.50)	40 minutes (E/P = 0.67)	50 minutes (E/P = 0.83)	60 minutes (E/P = 1.00)

Which, considering that FCR requires both **upward and downward regulation,** for storage technologies means an energy capacity that entails the following durations:

1 New LER dedicated to FCR provision – duration with degradation

Considering the expected battery degradation is necessary in order **to guarantee the provision of FCR** according to the **duration minimum requirements** all over the **lifetime of the system** (15 years)

According to the literature review, batteries degradation has two dimensions:

- **calendar ageing**
- **cycle ageing**

Academic source for the battery degradation formula used in the calculation:

Stroe, D., Swierczynski, M., Stroe, A., Laerke, R. Kjaer, P.C., Teodorescu, R. (2016) Degradation Behavior of Lithium-Ion Batteries Based on Lifetime Models and Field Measured Frequency Regulation Mission Profile. IEEE Transactions on Industry Applications IEEE Trans. on Ind. Applicat. Industry A.pplications, IEEE Transactions on. 52(6):5009-5018 Jan, 2016. https://doi.org/10.1109/TIA.2016.2597120

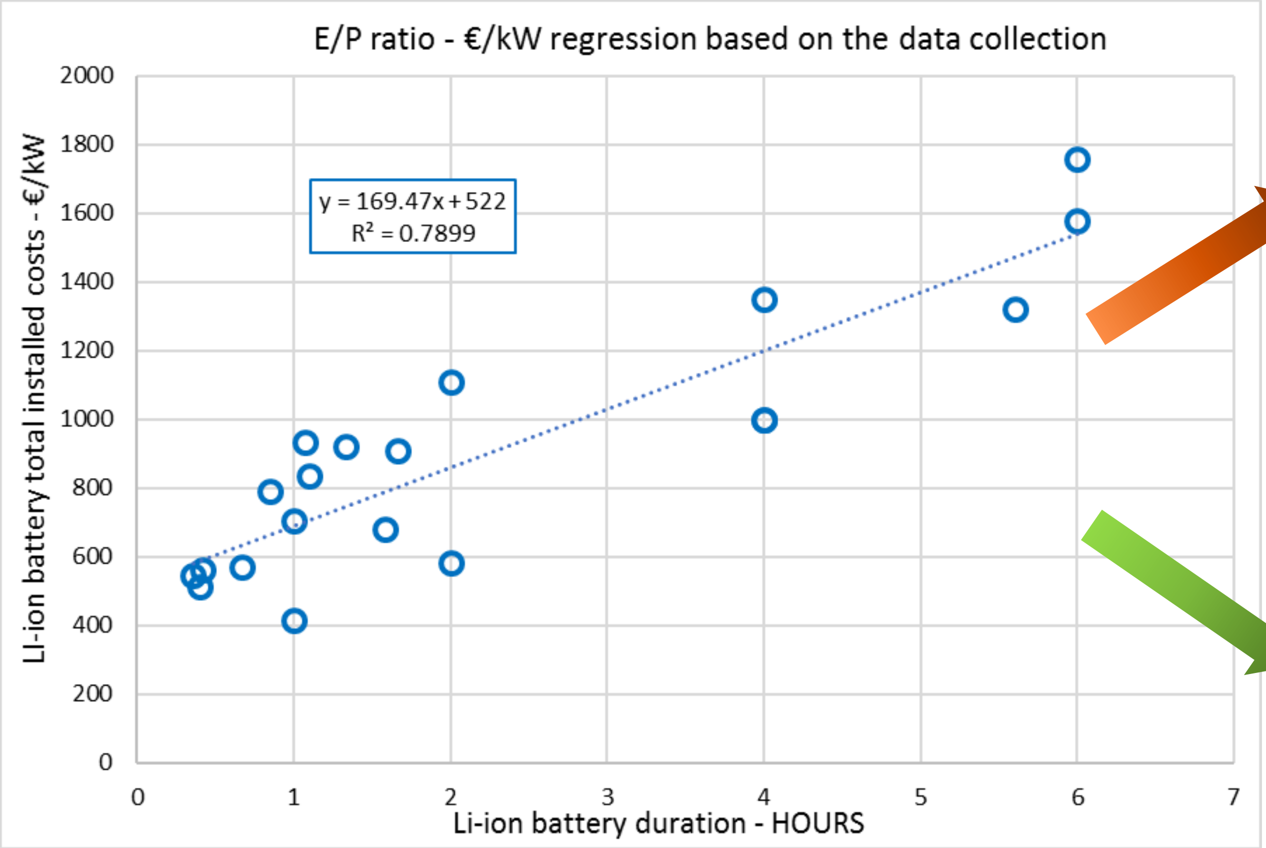
The expected degradation has been included in the analysis **as higher CAPEX at the time of the investment***

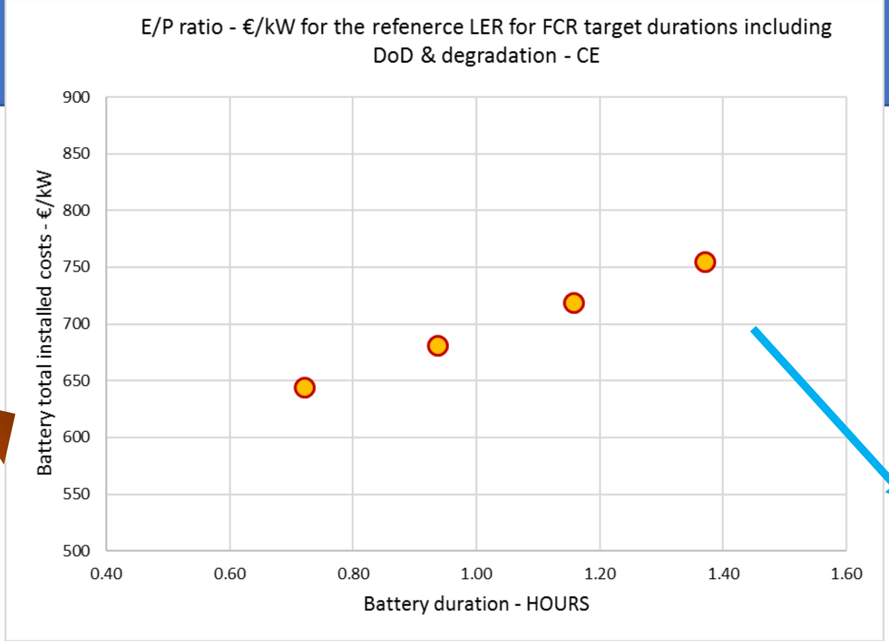
*This can be seen as an alternative to capital investments needed during the lifetime of the battery, which would require making more hypothesis about expected future trends

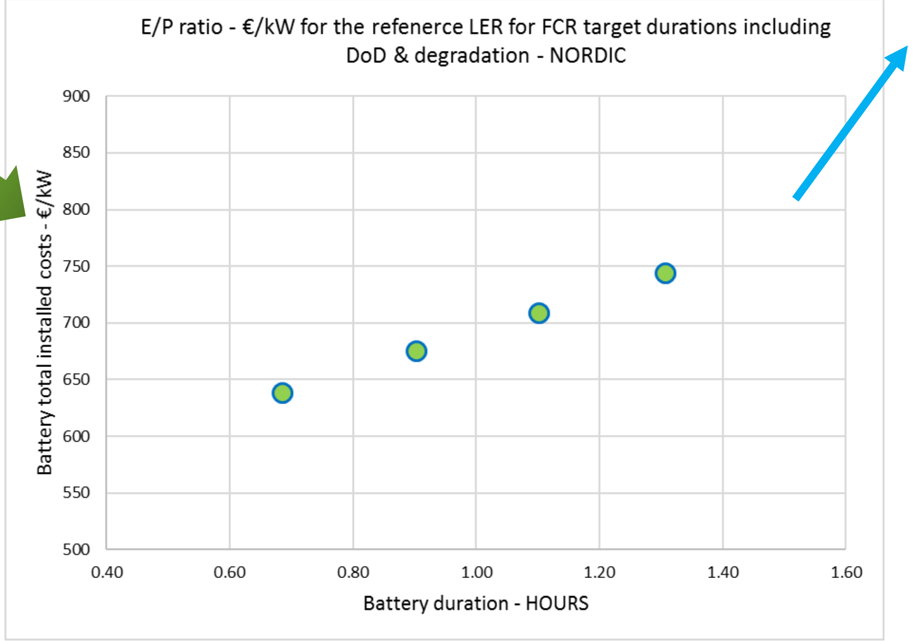
The cost analysis has been conducted considering four durations:

	15 minutes	20 minutes	25 minutes	30 minutes
Which, considering **upward and downward regulation,** means an energy capacity that entails the following durations:	30 minutes (E/P = 0.50)	40 minutes (E/P = 0.67)	50 minutes (E/P = 0.83)	60 minutes (E/P = 1.00)
Which, considering the expected energy degradation over a 15 years lifetime, entails investments with higher durations	**30* (1+xx%) minutes E/P = 0.50 * (1+xx%)**	**40* (1+xx%) minutes E/P = 0.67 * (1+xx%)**	**50* (1+xx%) minutes E/P = 0.83 * (1+xx%)**	**60* (1+xx%) minutes E/P = 1.00 * (1+xx%)**

1 New LER dedicated to FCR provision – regression analysis for CAPEX







Since the cycle ageing computation is based on actual historical frequency trends, the final degradation and, accordingly, CAPEX, are different in CE and Nordic

- Regression analysis based on data from 20 projects/cases
- The original data refer to projects/costs from different reference years
- For consistently performing the regression analysis all costs have been reported to year 2020 (in real €/2019 terms) based on IRENA's costs outlook (Electricity storage and renewables: Costs and markets to 2030, October 2017)

1 New LER dedicated to FCR provision – main inputs and results, CE

Main inputs/assumptions - CE	Technology	Reference year	Project lifetime	Discount rate	Battery size	OPEX (nominal value)	Round trip efficiency	Variable energy costs CE	Depth of Discharge - DoD	Battery energy capacity degradation over 15 years - CE	Final battery investment overdimensioning (including DoD + degradation) - CE
		year	years	%	MW	€/MW/Y	%	€/MW(h)	%	%	%
Parameter value - Tmin LER 15 mins	Li-ion Battery	2020	15	4.0%	10	8814	86.0%	0.19	90.0%	23.0%	44%
Parameter value - Tmin LER 20 mins	Li-ion Battery	2020	15	4.0%	10	9956	86.0%	0.19	90.0%	21.0%	41%
Parameter value - Tmin LER 25 mins	Li-ion Battery	2020	15	4.0%	10	11118	86.0%	0.19	90.0%	20.0%	39%
Parameter value - Tmin LER 30 mins	Li-ion Battery	2020	15	4.0%	10	12251	86.0%	0.19	90.0%	19.0%	37%

Regression analysis results for the target Tmin LER - CE	Duration - nominal	Duration - actual, for CAPEX calculation (including DoD & degradation)	CAPEX
	Hours	Hours	€/kW
Tmin LER 15 mins	0.50	0.72	644
Tmin LER 20 mins	0.67	0.94	681
Tmin LER 25 mins	0.83	1.16	718
Tmin LER 30 mins	1.00	1.37	754

Li-ion batteries FCR provision cost (long run marginal cost) - CE	FCR cost CAPEX + OPEX	FCR cost total (CAPEX, OPEX, energy) - CE
	€/MW(h)	€/MW(h)
Tmin LER 15 mins	7.66	7.86
Tmin LER 20 mins	8.17	8.37
Tmin LER 25 mins	8.69	8.89
Tmin LER 30 mins	9.20	9.39

Energy capacity degradation differentiated according to the battery duration

DoD: the max allowed discharge

OPEX (in €/MW/Y) differentiated according to the battery duration

- To calculate the variable costs for providing FCR it has been taken as a reference a round-trip-efficiency 86%.
- For volumes and costs, the calculation has been based on average historical frequency profiles and on average system marginal costs in 2020 (ENTSO-E's TYNDP 2018 scenario).

✓ For each duration, the specific investment cost, €/MW of one benchmark unit, is distributed among a number of annuities according to the project lifetime.

✓ Then the cost €/MW per one hour is calculated and used to construct the cost curve.

1 New LER dedicated to FCR provision – main inputs and results, NORDIC

Main inputs/assumptions - NORDIC	Technology	Reference year	Project lifetime	Discount rate	Battery size	OPEX (nominal value)	Round trip efficiency	Variable energy costs - NORDIC	Depth of Discharge - DoD	Battery energy capacity degradation over 15 years - NORDIC	Final battery investment overdimesioning (including DoD + degradation) - NORDIC
		year	years	%	MW	€/MW/Y	%	€/MW(h)			%
Parameter value - Tmin LER 15 mins	Li-ion Battery	2020	15	4.0%	10	8625	86.0%	0.17	90.0%	19.0%	37%
Parameter value - Tmin LER 15 mins	Li-ion Battery	2020	15	4.0%	10	9775	86.0%	0.17	90.0%	18.0%	36%
Parameter value - Tmin LER 15 mins	Li-ion Battery	2020	15	4.0%	10	10826	86.0%	0.17	90.0%	16.0%	32%
Parameter value - Tmin LER 15 mins	Li-ion Battery	2020	15	4.0%	10	11909	86.0%	0.17	90.0%	15.0%	31%

Regression analysis results for the target Tmin LER - NORDIC	Duration - nominal	Duration - actual, for CAPEX calculation (including DoD & degradation)	CAPEX
	Hours	Hours	€/kW
Tmin LER 15 mins	0.50	0.69	638
Tmin LER 20 mins	0.67	0.90	675
Tmin LER 25 mins	0.83	1.10	709
Tmin LER 30 mins	1.00	1.31	744

Li-ion batteries FCR provision cost - NORDIC	FCR cost CAPEX + OPEX	FCR cost total (CAPEX, OPEX, energy) - Nordic
	€/MW(h)	€/MW(h)
Tmin LER 15 mins	7.60	7.76
Tmin LER 20 mins	7.99	8.15
Tmin LER 25 mins	8.34	8.51
Tmin LER 30 mins	8.71	8.88

OPEX (in €/MW/Y) differentiated according to the battery duration

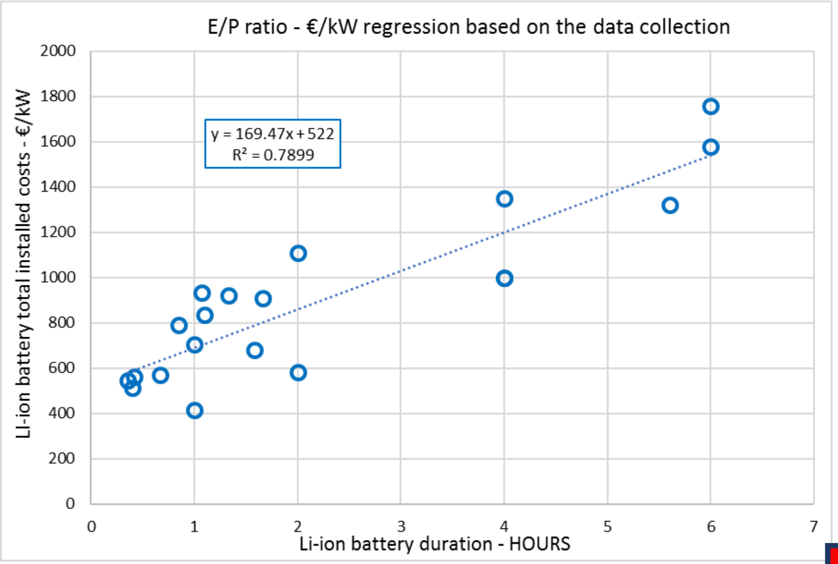
- To calculate the variable costs for providing FCR it has been taken as a reference a round-trip-efficiency 86%.
- For volumes and costs, the calculation has been based on average historical frequency profiles and on average system marginal costs in 2020 (ENTSO-E's TYNDP 2018 scenario).

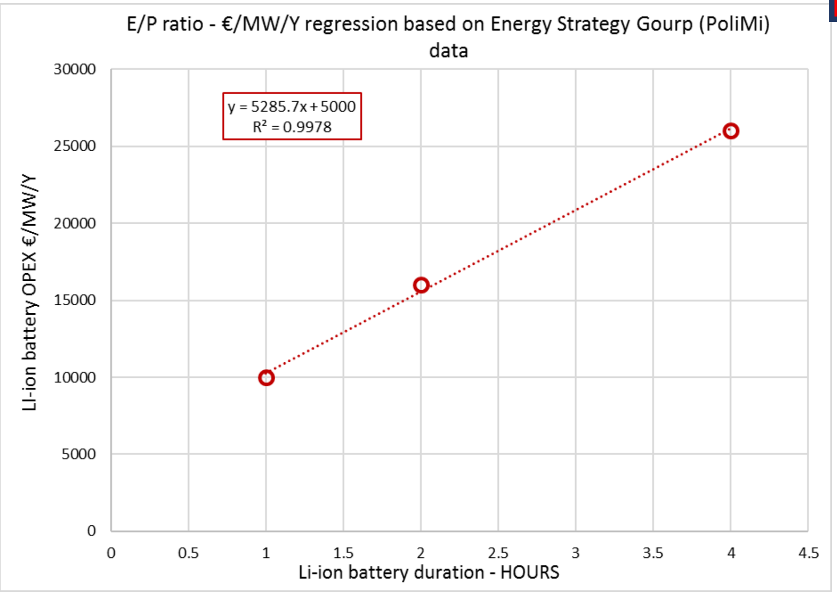
DoD: the max allowed discharge

Energy capacity degradation differentiated according to the battery duration

- ✓ For each duration, the specific investment cost, €/MW of one benchmark unit, is distributed among a number of annuities according to the project lifetime.
- ✓ Then the cost €/MW per one hour is calculated and used to construct the cost curve.

1 New LER dedicated to FCR provision – Costs differentiation according to the duration





Li-io Batteries total installed costs (total CAPEX for turnkey solutions) do not increase proportionally to the increase in the E/P ratio

- ➢ They include some costs which are partially independent from the energy capacity of the battery:
  - ❑ Power electronics
  - ❑ Grid connection
  - ❑ Civil works

  Such costs have a high impact in €/MW especially when considering solutions with relatively low and not highly differentiated E/P ratios
- ➢ OPEX do not increase proportionally to the increase in the E/P ratio

❷ New LER non specifically commissioned for FCR provision

Non-expressly commissioned for providing FCR, but that can reserve part of their energy capacity for FCR provision

2020: only currently available technologies to be considered: electricity storage systems (stationary + mobile, EVs)

- Total installed capacity? Scenarios assumptions → ENTSO-E's 2018 TYNDP
- Quota to be reserved for FCR? scenario assumptions or current share of existing LER

Which costs?

- CAPEX
- Degradation costs
- Opportunity costs
- Variable costs

ENTSO-E's 2018 TYNDP for 2020:

- NO specific assumptions about new stationary ESSs
- 1.7 million new electric vehicles → but V2G still at pilot project stage

>>> Assumed equal to be substantially absent (zero volumes) in 2020 <<<

3 Existing LER

Which costs?

- CAPEX
- Degradation costs
- Opportunity costs
- Variable costs

Calculated in the same way of the variable energy costs for new LER dedicated to FCR provision for batteries & EVs

Variable energy costs	
CE €/MW(h)	NORDIC €/MW(h)
0.19	0.17

Assumed substantially equal to zero for other technologies

Volumes?

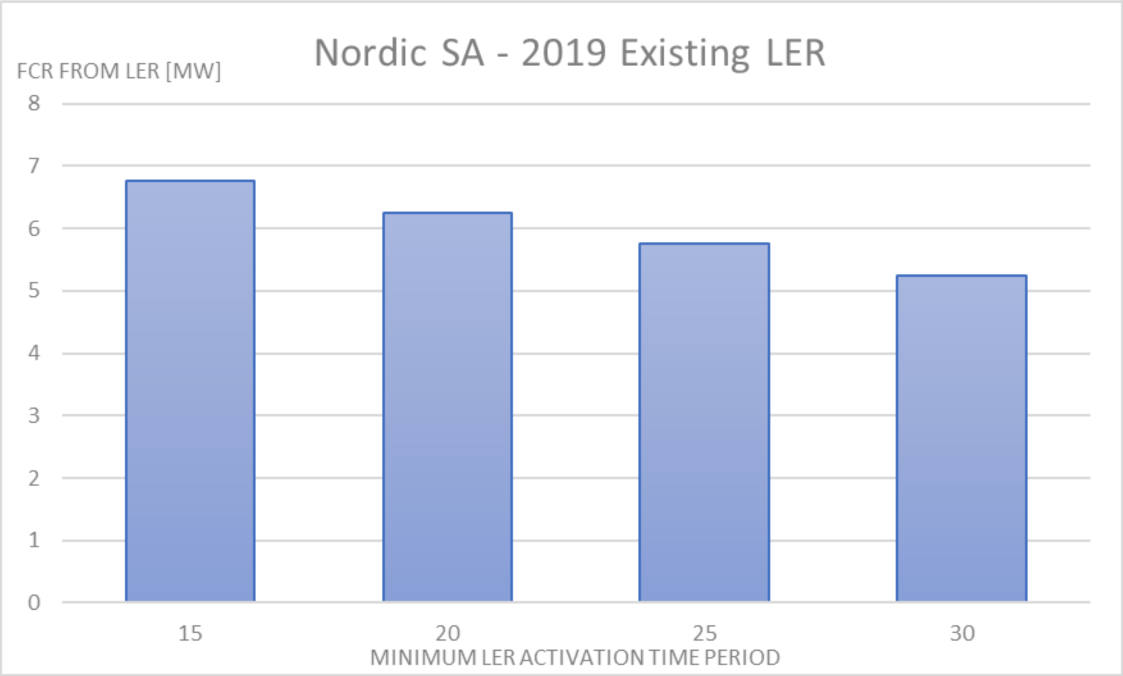
SURVEY

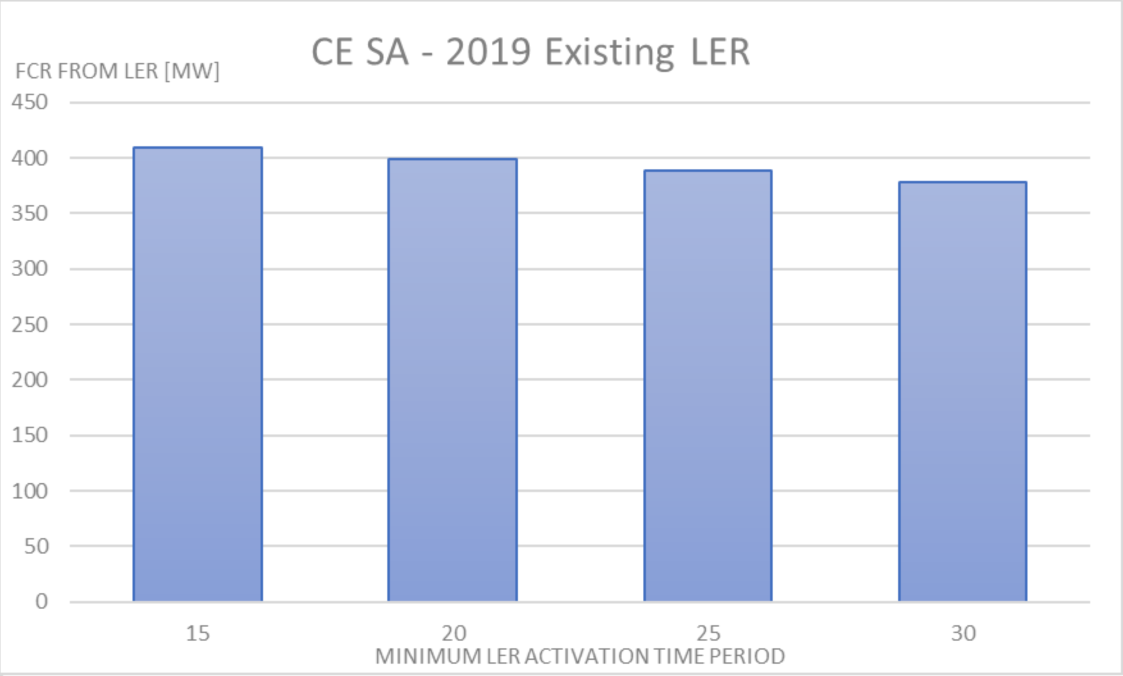
- Two questions on the qualified capacity for FCR provision and the total installed capacity of all technologies (both LER and non-LER) according to their duration and E/P ratio

- **Survey deadline: 5 September 2019**

3 Existing LER – volumes according to survey results

Effect of different minimum activation Time Period on electrochemical storage in both SAs

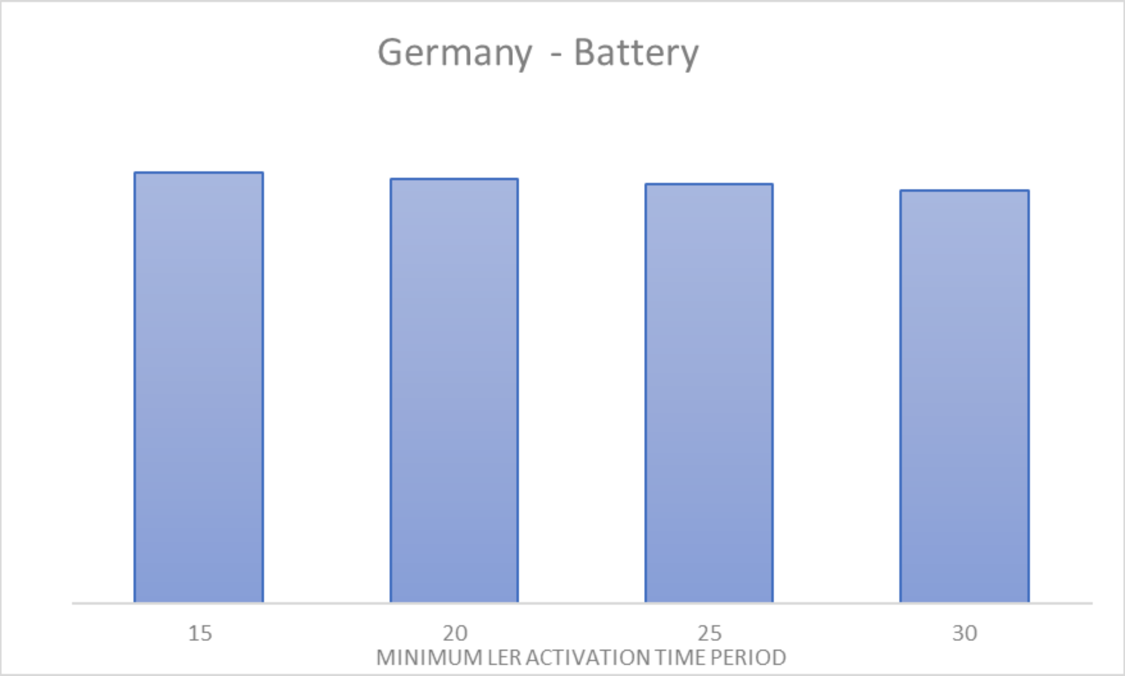




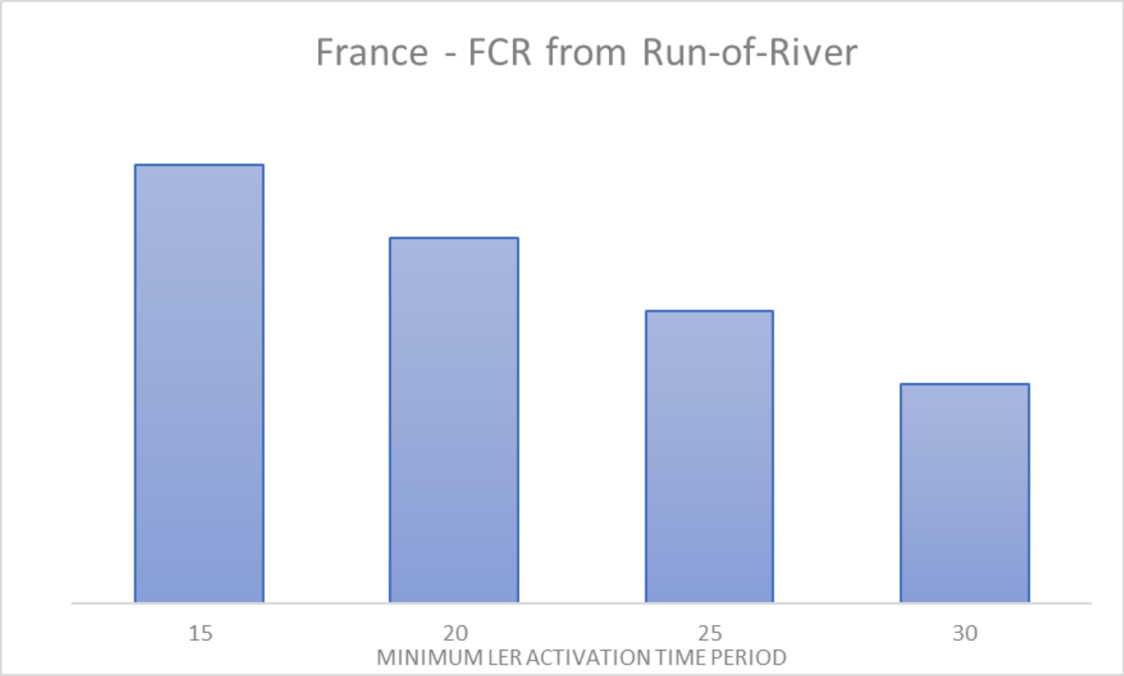
According to the survey results, the available FCR provided by LER has been estimated for different minimum activation time period.

Different Minimum Activation Time affects existing FCR providers

The effects of different Minimum Activation time on existing LER are taken into account using the results of the survey performed amongst TSO's. The offered quantity in the costs curves are modified for the different Minimum Activation Times (15' -> 30').



e.g.
In Germany the effect of actual available FCR provided by Battery Storage due to TminLER changes are minimal.



e.g.
In France the FCR provided by run-of river is approximately halved if the TminLER change from 15' to 30'.

Non-LER for FCR provision: data sources

ENTSO-E 2018 TYNDP
- ✓ reference average marginal generation cost per country (taken as a proxy of the country DAM average 2020 price)
- ✓ commodities (fuels and CO2) prices for 2020
- ✓ efficiencies, emissions factors, variable O&M costs

ENSTO-E Mid-term Adequacy Forecast (MAF) 2018
- ✓ available capacity per technology per country in 2020

ENTSO-E transparency platform for further data needed for hydro resources (pumped-hydro in particular)
- ✓ Current (2018, which is the last full year available) hourly DAM prices per country
- ✓ Current (2018 – 2019) installed pumped-hydro capacity per country (not explicitly reported in the TYNDP and MAF datasets)
- ✓ Current (2018, last full year available) actual hourly generation per technology (type) per country

➡ **Survey results** for the volumes (MW) per technology for each respondent country

➡ For the other countries: the results (November 2018) in terms of pre-qualified capacity in the German tenders for primary control reserve have been used as a proxy of the quotas of the total capacity per technology that is reserved/used for FCR provision

Non-LER costs: DAM vs primary reserve market

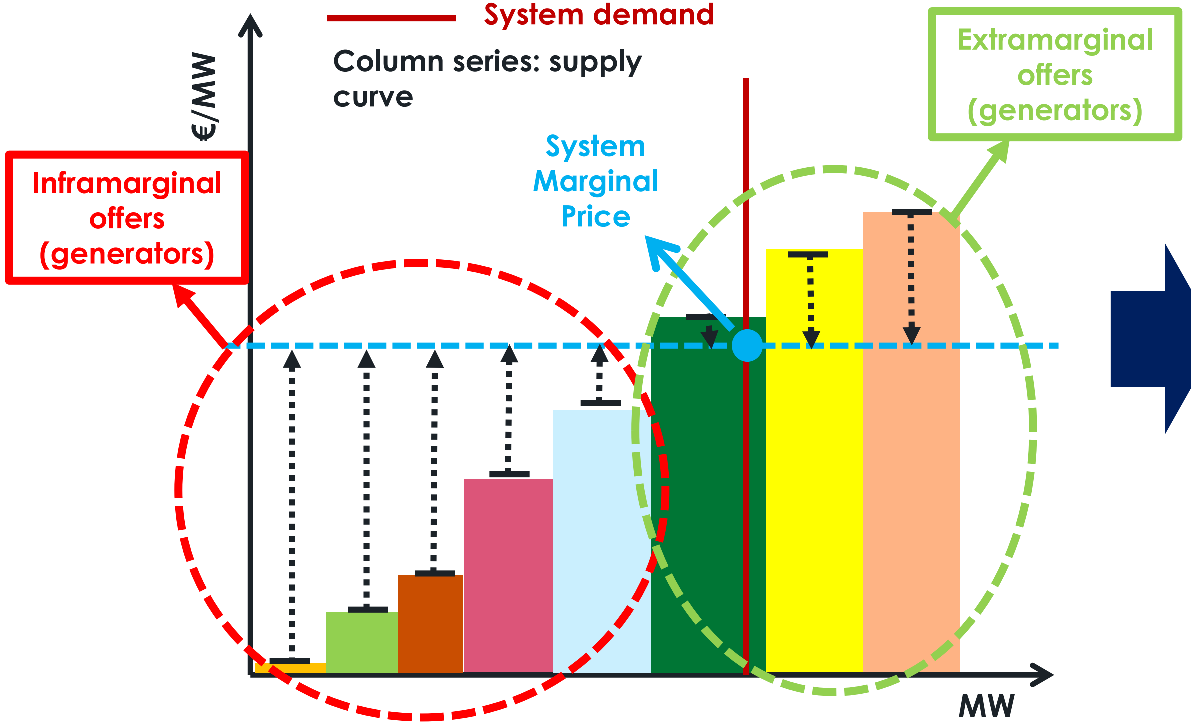
Day-ahead markets (DAMs):

- **System marginal price** markets
- **Inframarginal and extramarginal** electricity generation units

N.B.: the analysis is actually based on the average marginal generation costs for 2020 reported in ENTSO-E 2018 TYNDP, taken as a proxy of the country DAM average 2020 price

The difference between price and costs is the operators' market strategy (bid-up)

Variable generation costs vs DAM prices (opportunity costs)

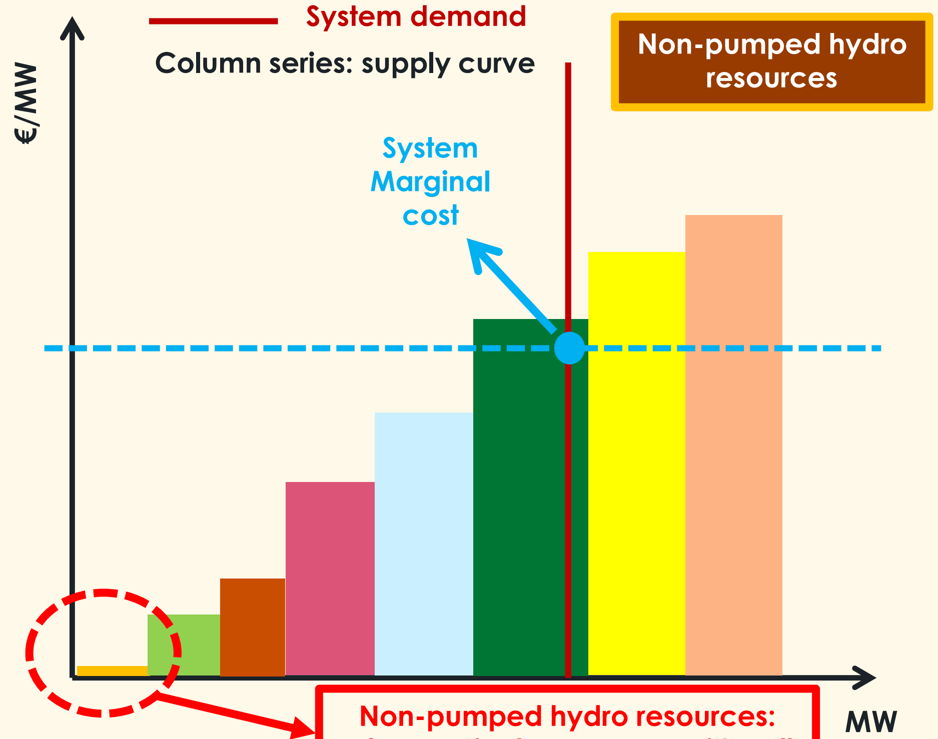


Inframarginal offers (generators) → FCR cost for one MW(h) = System Marginal Price - Generator variable costs

Extramarginal offers (generators) → FCR cost for one MW(h) = Generator variable costs - System Marginal Price

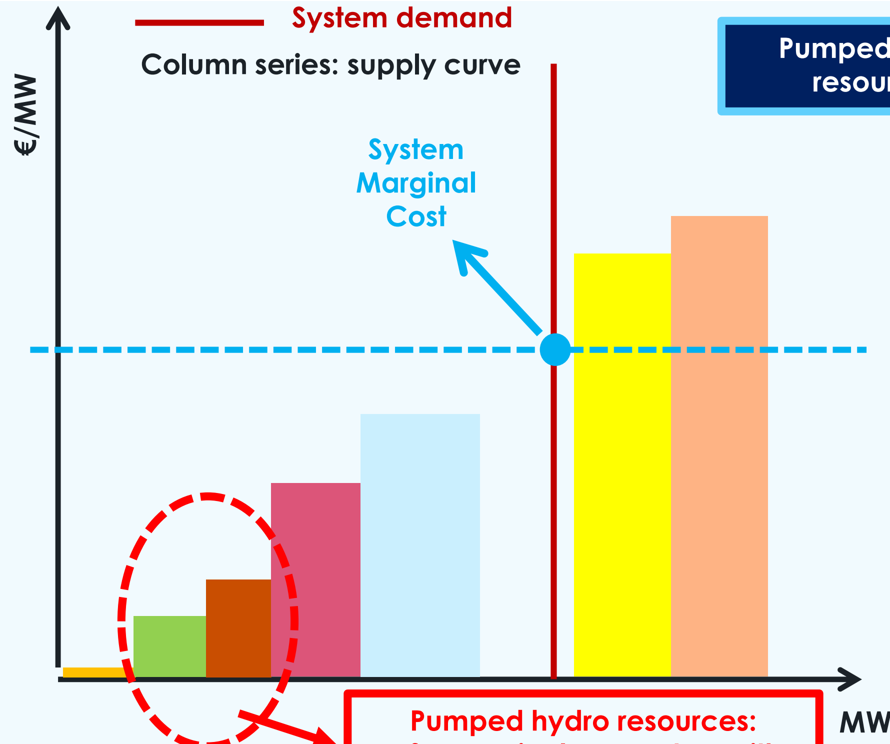
The closer the variable cost of the generator are to the system marginal price…
… the lower the cost for providing FCR is

Non-LER costs: hydro resources



Non-pumped hydro resources: Inframarginal generators with null variable costs (0 €/MWh)

Similarly to other renewables, non-pumped hydro has zero "fuel" (variable) cost: the cost of water



Pumped hydro resources: Inframarginal generators with very low variable costs, but higher than non-pumped

Similarly to thermal power plants, pumped hydro has a "fuel" cost: the cost of electricity to pump water (divided by the efficiency)

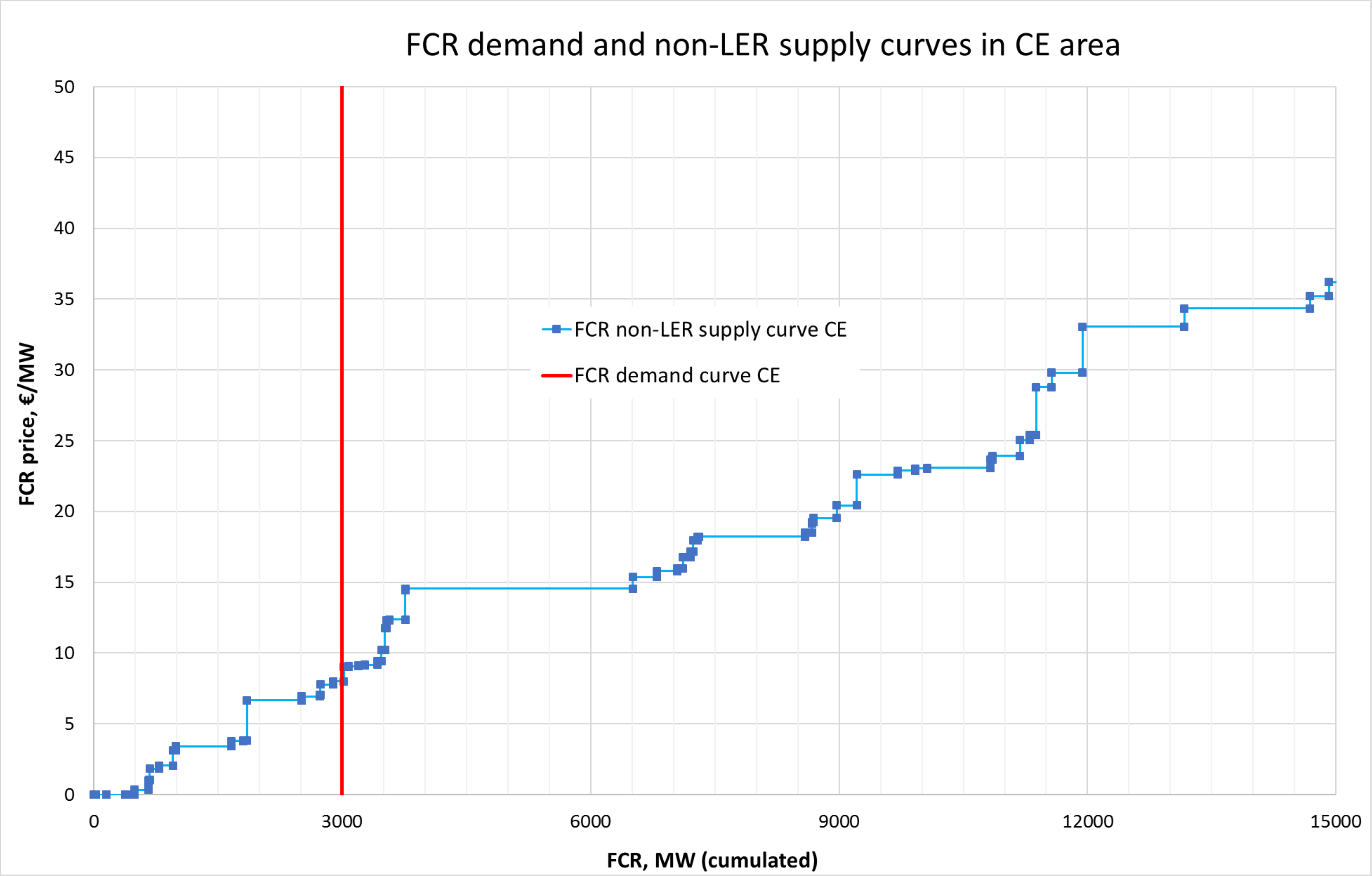
Assumption: electricity consumptions during the XXX hours of the year with the lowest costs (prices)

Which hours/how many hours?

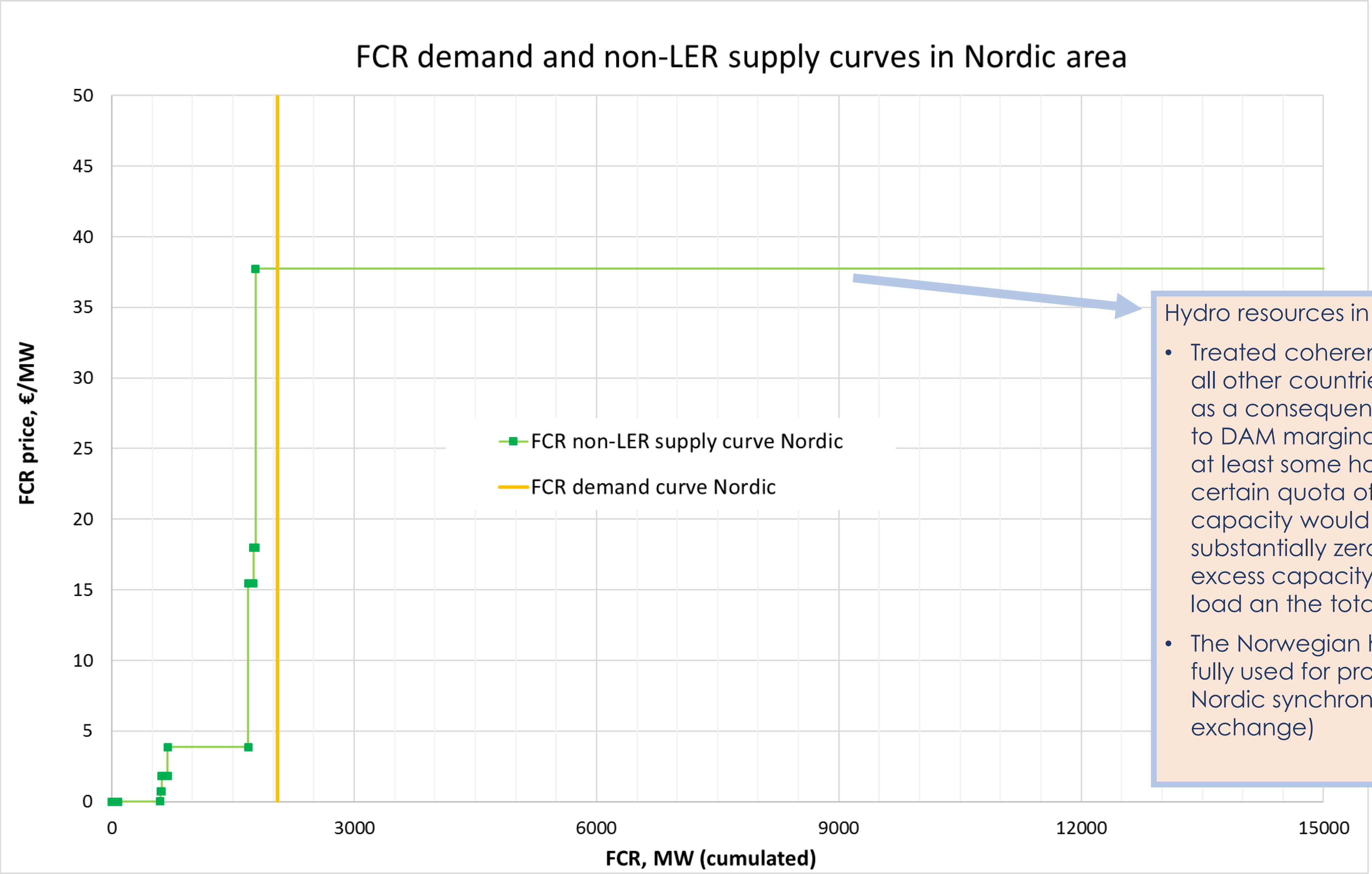
- >> Analysis of pumped-hydro market behaviour and DAM prices in 2018 to evaluate the number of hours with the lowest prices that should be considered in each country

Assumption: the technical and economic constraints of pumped-hydro power plants can be inferred from their bidding/generation behaviour on the DAM

Non-LER cost curve, CE



Non-LER cost curve, NORDIC



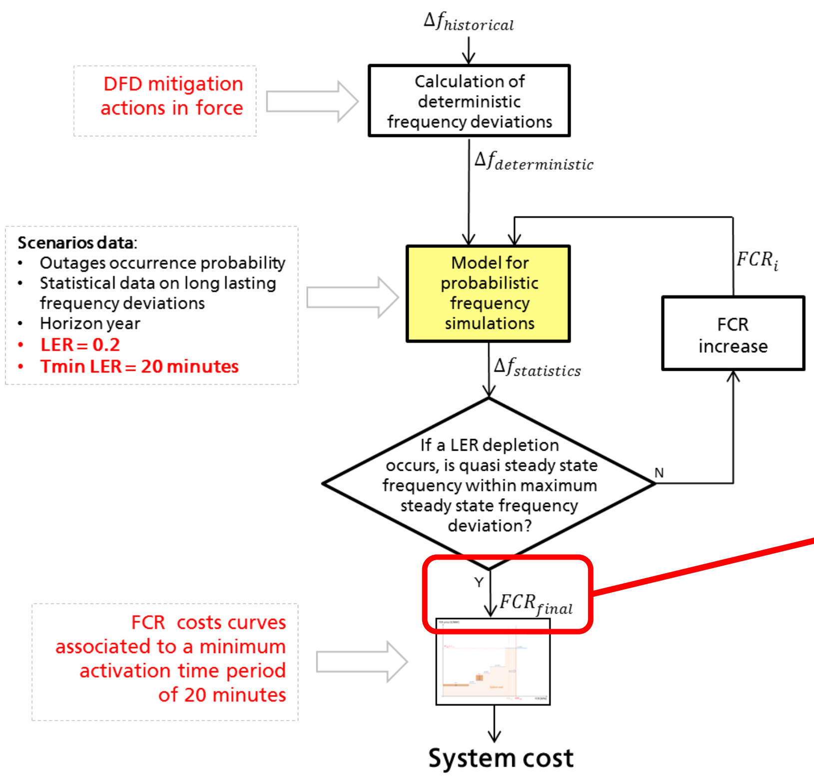
Hydro resources in Norway:

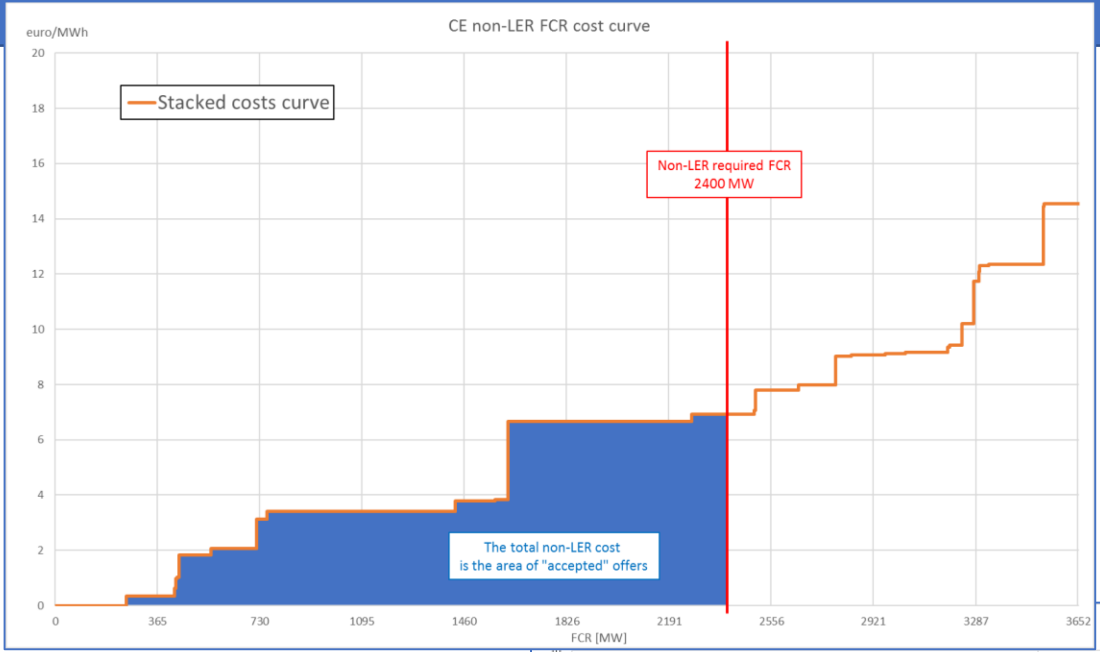
- Treated coherently with hydro resources in all other countries (variable cost = 0, and, as a consequence, opportunity cost equal to DAM marginal cost), although there are at least some hours during the year when a certain quota of the Norwegian hydro capacity would provide FCR at substantially zero price (when there is excess capacity considering the national load an the total export capacity)
- The Norwegian hydro resources cannot be fully used for providing FCR to the whole Nordic synchronous area (limits on FCR exchange)

Examples of use of costs in a simulated scenario (CE)

e.g. Scenario with:

- 20% LER Share
- 20’ of minimum activation time period
- Presence of DFD mitigation

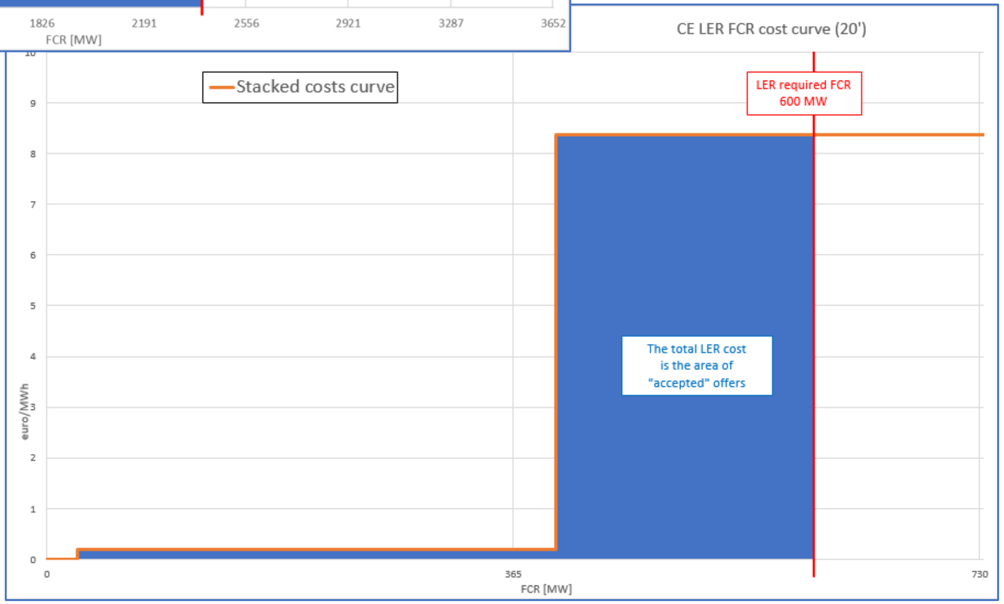




Non-LER curve

In the CBA only the costs to provide FCR are considered. To minimize these costs means to maximize the social welfare (surplus producers + surplus consumer).

LER curve

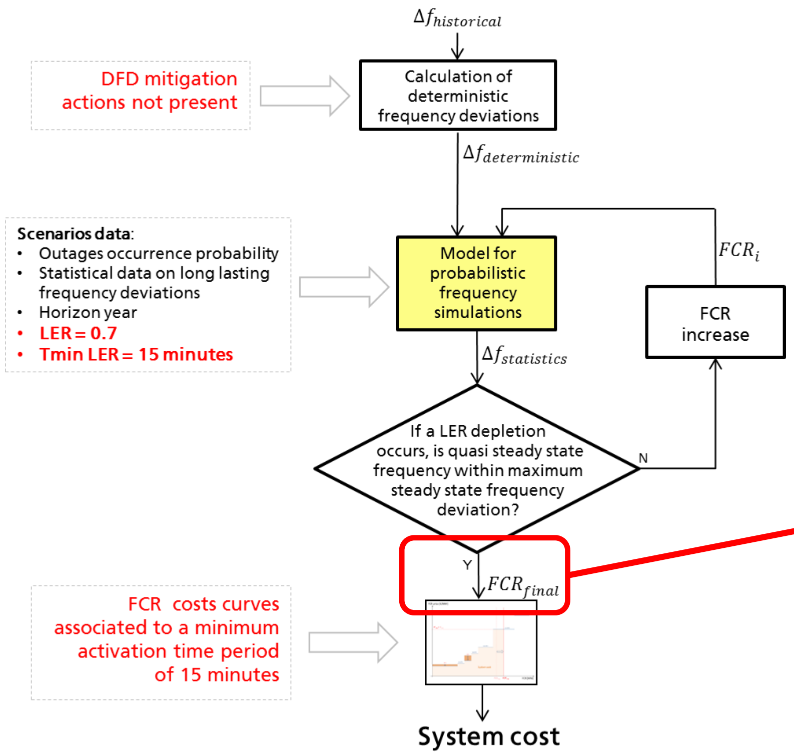


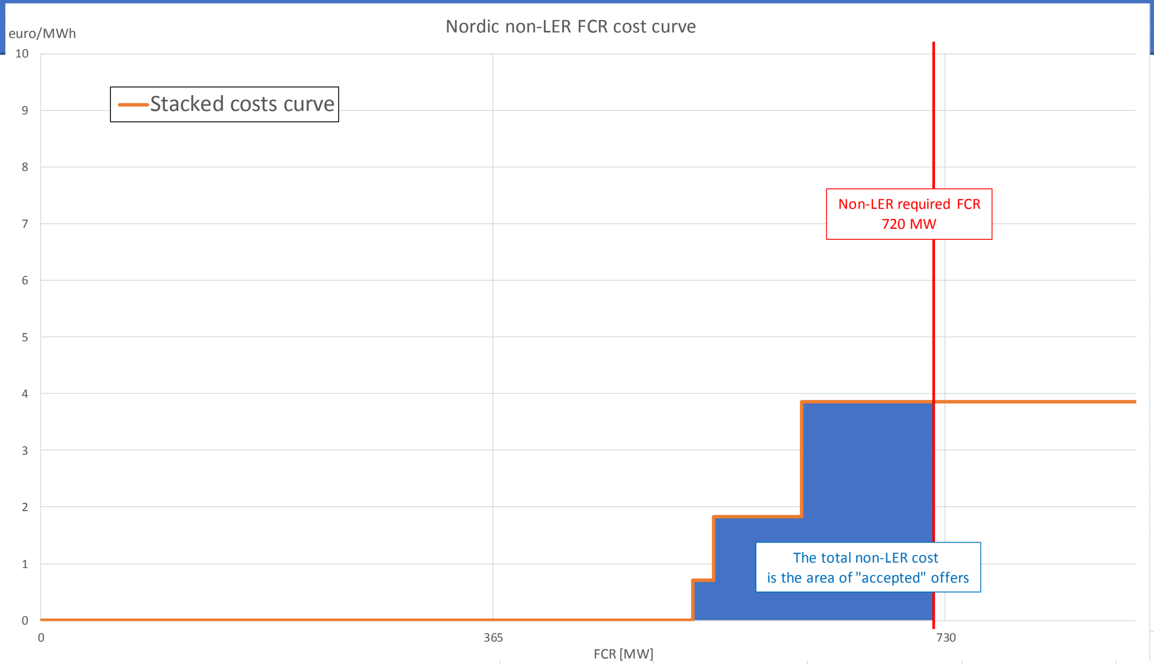
e.g. The output of the MC model **could be** that no additional FCR is required. 20% of LER having 20’ of minimum activation time period does not affect the system security.

Examples of use of costs in a simulated scenario (Nordic)

e.g. Scenario with:

- 70% LER Share
- 15’ of minimum activation time period
- Absence of DFD mitigation

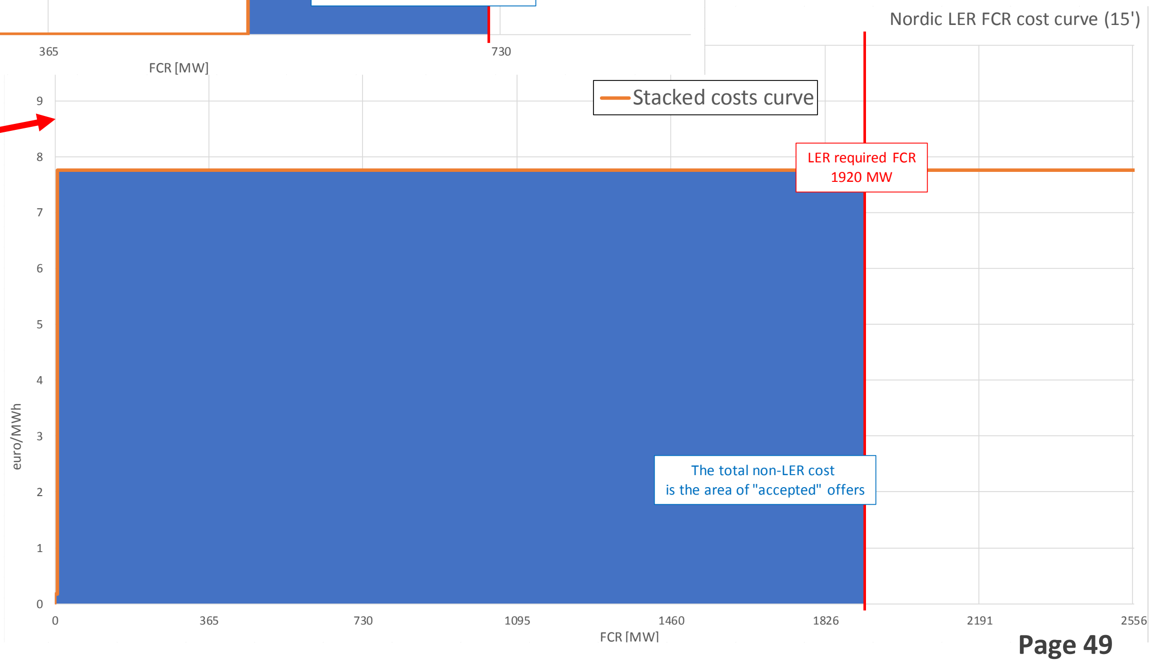




Non-LER curve

In the CBA only the costs to provide FCR are considered. To minimize these costs means to maximize the social welfare (surplus producers + surplus consumer).

LER curve



e.g. The output of the MC model **could be** that additional FCR is required. In this example 2400 MW of FCR are required (instead of 2050 MW)