# Workshop agenda

| No | Subject | TIME | WHO |
|---|---|---|---|
| 1 | **Workshop Opening** | 10:00-10:10 | L. Ortolano |
| 2 | **Update of FCR costs for the CBA** | 10:10-11:10 | D. Dresco |
| | **Coffee break** **22** 11:10-11:20 | | |
| 3 | **Technical input of the CBA** | 11:20-12:00 | L. Ortolano |
| | **Lunch break** 12:00-13:00 | | |
| 4 | **Mitigation actions against LLEFD** | 13:00-14:15 | L. Ortolano/TSO SPOCs |
| 5 | **Closing remarks** | 14:15-14:30 | L. Ortolano |

# CBA for Tmin LER definition

## Framework and scope

According to Art.156(10) SO GL, TSOs shall develop a common proposal concerning the minimum activation period to be ensured by FCR LER during alert state (TminLER).

The proposal shall take full account of the results of the CBA conducted pursuant to Article 156(11) of SOGL. The proposal is subject to NRAs' approval.

Timeline:

- *October 2021: NRAs approve the CBA methodology proposed by TSOs.*
- *December 2021: TSOs submitted their first proposal for a TminLER.*
- *December 2022: NRAs issued a __Request for Amendment__ on TSOs' proposal.*

- CE NRAs request TSOs to **__run a new instance of the CBA__** methodology after **__having updated some of the key input__** regarding frequency and FCR costs.

- Following the agreed steps, the Project Team FCR by LER prepared a report on the detailed data and assumptions to be used in the CBA, on public consultation by 31 March 2024, which includes:
  - The updated costs of FCR provided by LER
  - The updated technical inputs, in particular regarding historical frequency trend and outages assumptions

# Input update for CBA for LER

- *Introduction and legal framework for costs definition*
- *LER Costs*
  - *New LER dedicated to FCR provision*
  - *New LER non-specifically commissioned for FCR provision*
  - *Existing LER*
- *Non-LER Costs*

- *Technical data update*
  - *Outages data for generation units*
  - *Outages data for HVDC connections*
  - *Frequency dataset*

# Costs of LER & non-LER

## Legal Framework

- For the re-run of the CBA methodology (Art.156(11) SO GL) is requested to update FCR costs for both LER and non-LER.

- **CBA methodology for FCR Proposal***, underlying the costs data collection process, is considered valid, especially Article 5 concerning FCR cost assessment:
  1. FCR cost curve shall **include both LER and non-LER** FCR providers.
  2. The FCR **cost for non-LER** FCR providers shall be calculated at least by **comparing** the **marginal cost** of the FCR provider with the **day-ahead energy marginal price** of the bidding zone. The comparison allows to estimate the cost of reserving capacity for FCR provision.
  3. The FCR cost for **future installed LER** shall be calculated considering **investment, OPEX** and opportunity costs (if any), only if they are sustained to qualify for FCR provision
  4. The FCR cost for already **existing LER** shall be calculated considering: **OPEX** and opportunity costs (if any), only if they are sustained to qualify for FCR provision.
  5. The impact on FCR cost for LER due to variations of energy reservoir requirement (associated to the Time Period) shall be considered.

* 2/03/2019, *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*

# Costs of LER & non-LER

## General assumptions

The cost analysis has a **short-term time horizon to limit the level of uncertainty about the expected technological and costs evolution**.

→ **2025 is proposed as the reference** year both for LER and non-LER resources

- For non-LER resources recent historical spot prices are the main source for scenario data, based on the assumption of price stability in the near term after the pandemic and Ukraine war market shocks
- For new LER specifically commissioned for FCR provision 2025 is the investment year (and the commissioning year)
- The resulting FCR cost curves refer to year 2025

All **costs/prices are expressed in real terms in € 2023** (ECB yearly average exchange rates and IMF inflation rates are used where needed)

# LER Costs

# LER for FCR Provision

## Three categories are analysed

**1 New LER dedicated to FCR provision** ✓

All sources point to **Li-ion technology** as the most competitive for FCR application

**2 New LER non-specifically commissioned for FCR provision** ✗

**3 Existing LER** →

- CAPEX
- Degradation costs
- **Fixed OPEX**
- **O&M costs** →
  - *Same as new LER for* ***batteries*** *(fixed* ***OPEX and charging cost****)*
  - *Zero for other tech*

✓

# LER for FCR Provision

## Sourced used for the study

Sources have been updated and expanded from previous analyses (2019)


1. IRENA – “Electricity storage evaluation framework: assessing system value and ensuring project viability” (2020)
2. IEA – “World Energy Investment 2023”
3. LAZARD – “Levelised Cost of Storage Analysis – Version 7.0” (April 2023)
4. U.S. EIA – “Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies” – (2020)
5. U.S NREL – “Storage future study-Storage Technology Modelling Input Data Report” – (2022)
6. U.S NREL – “Storage future study-key learnings for the coming decades” – (2022)
7. U.S NREL– “Utility Scale BESS 2022 Annual Technology Baseline” – (2022)
8. U.S. NREL and Sandia National Laboratories– “2019 Energy Storage Pricing Survey” – (2021)
9. U.S DOE Pacific Northwest National Laboratory – “2022 Grid Energy Storage Technology Cost and Performance Assessment” (2022)
10. U.S. Department of Energy - Global Energy Storage Database - https://energystorageexchange.org/
11. Energy Transition Expertise Centre for European Commission – “Study on Energy Storage” (2023)
12. Joint Research Centre EU (JRC) – Batteries for energy storage in the European union (2022)
13. Journal of Energy Storage – “The development of stationary battery storage systems in Germany –A market review” (2020)
14. Energy & Strategy Group (Polytechnic University of Milan) – “Energy Market Report” – (2022)
15. The European Association for Storage of Energy (EASE)
16. Press releases and other documents from different stakeholders on specific project

# New LER dedicated to FCR provision 1

## Long Term Marginal Cost

For new LER specifically commissioned for FCR provision the cost curve definition **is based on the Long-Run Marginal Cost concept**, where all production factors are endogenous:

- Investment cost or CAPEX [€/MW]
- Yearly fixed Operation and Maintenance costs or OPEX [€/MW/year]

### LONG TERM MARGINAL COST CALCULATION

**CAPEX** [€/MW] is distributed among a number of **annuities.**

It depends on:
- WACC
- Units' lifetime
- Paid at t=0
- End-of-Life value=0
- LER duration

**OPEX*** [€/MW/yr] is calculated for each year in project lifetime.

It depends on:
- WACC
- Units' lifetime
- LER duration

**Equivalent Annual Cost** [€/MW·h] for providing FCR
- WACC
- Units lifetime
- LER duration

\+

**Variable cost** [€/MW·h] to to compensate for roundtrip efficiency
- Roundtrip efficiency
- DAM avg prices
- Avg historical frequency profile

**FCR LER Cost €/MW per one hour** used to construct the cost curve, **for each LER duration**

**Dependence from LER duration according to selected sources from literature review*

# New LER dedicated to FCR provision 1

## Methodological steps for CAPEX estimation

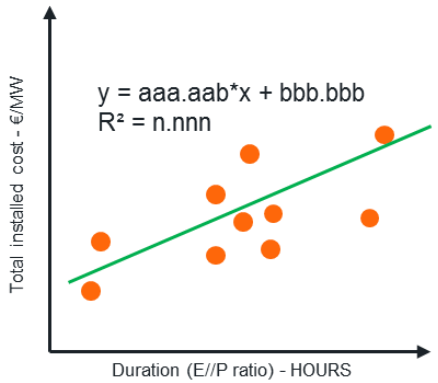
1. Collection of **recent/current CAPEX** data (€/kW – total installed cost) differentiated according to:
    - the specific technology considered
    - the size cluster (MW of installed power) of interest
    - the LER duration (Energy to Power – E/P – ratio)
    - the investment/commissioning year

2. Current **CAPEX** (€/kW) for the different target durations are projected in the **future reference year 2025** according to **technologies costs projections** (7), expressed in **real terms in €2023**.

**CAPEX [€2025]= project CAPEX * (1 - expected % cost decrease)**

3. Based on the data collected, a **regression analysis** is performed to **estimate the relation** between the **duration** (E/P ratio - independent variable) **and the investment cost** (€/kW – dependent variable) of Li-ion batteries.

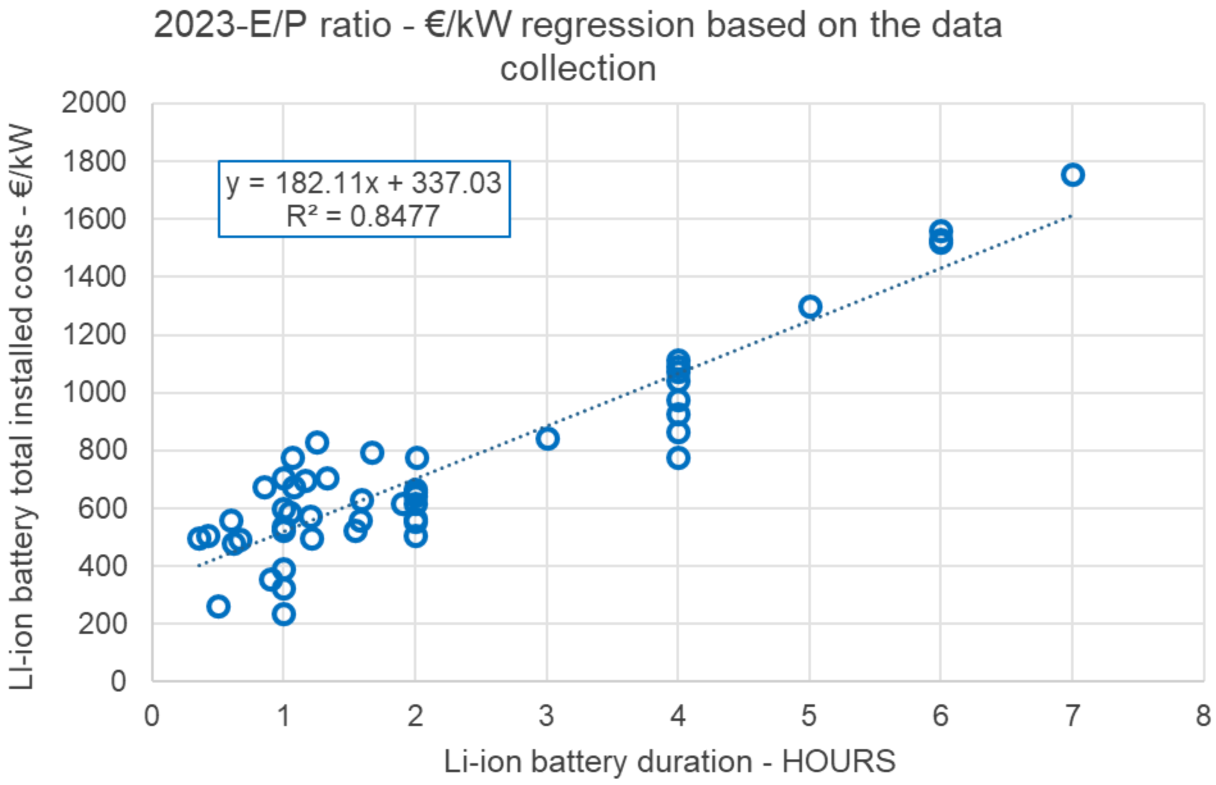
4. The resulting linear equation is used to estimate the current CAPEX (€/kW) for the d**ifferent target durations***.

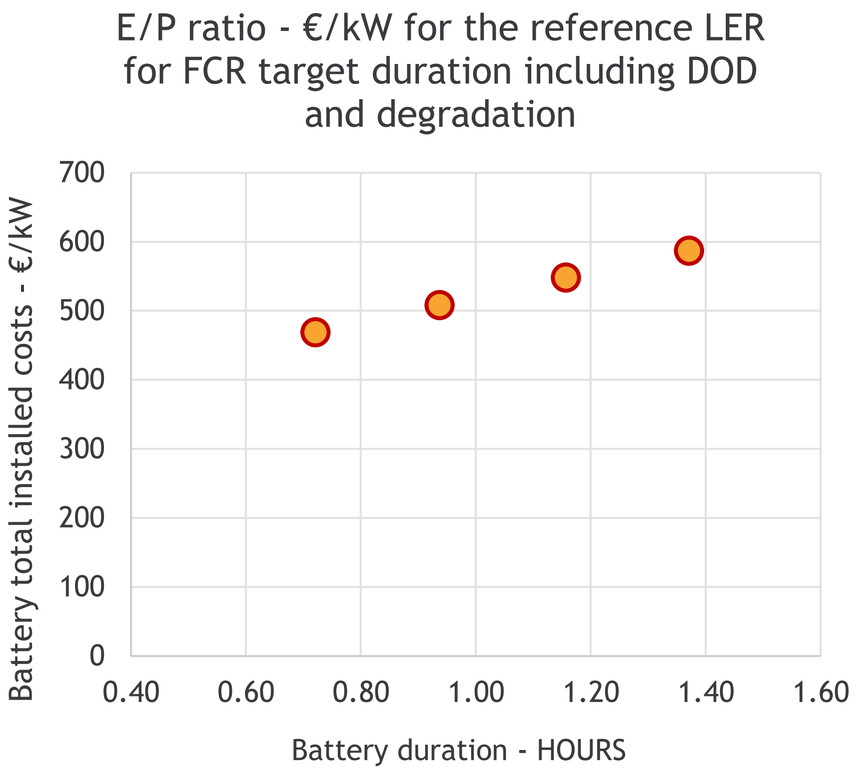



* **Target durations are over dimensioned** to **guarantee minimum duration requirements all over the lifetime** of the system due to degradation and dept of discharge parameter (higher CAPEX at the time of the investment)

# New LER dedicated to FCR provision ❶

## 2023 regression analysis for CAPEX




- Regression analysis based on data from 50 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 2025 (in real €/2023 terms) based on NREL study** (7).

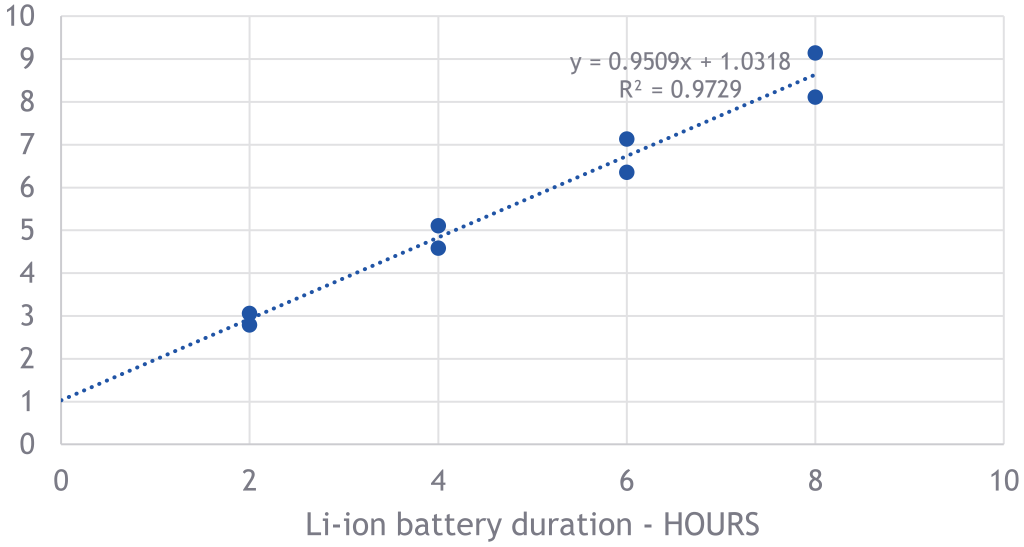
# New LER dedicated to FCR provision 1

## OPEX Estimation

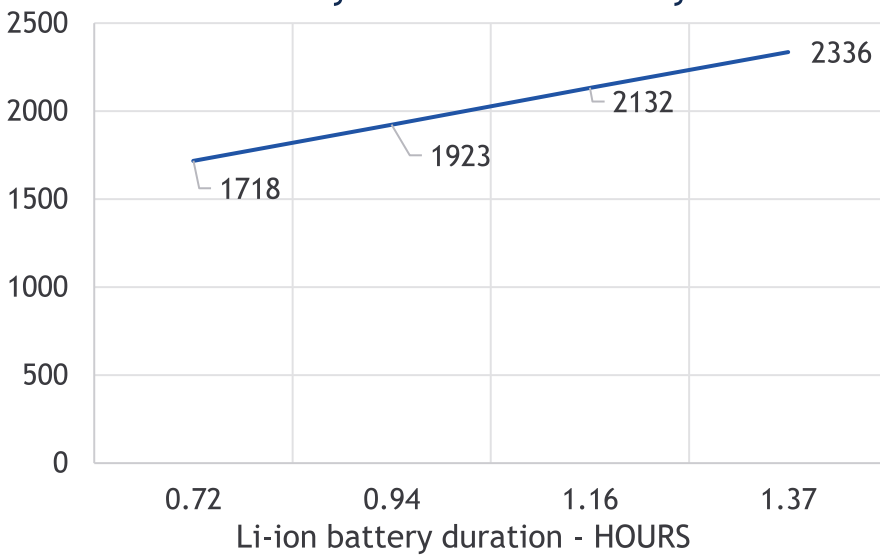
*Source (9): "2022 Grid Energy Storage Technology Cost and Performance Assessment", U.S DOE Pacific Northwest National Laboratory*

- OPEX or Operation and maintenance (O&M) costs include all costs needed to keep storage equipment operating.
- Fixed O&M costs include all necessary costs that are not based on usage (i.e., costs that need to be paid no matter what the use case is) but exclude cost of augmenting storage system due to degradation.

DOE ESGC fixed O&M real 2023 [€/kW/yr]




Battery fixed OPEX €/MW/yr




**Variable O&M cost** is calculated as the energy cost to compensate for roundtrip efficiency.

# New LER dedicated to FCR provision 1

## 2023 analysis main inputs and results

| Main inputs/assumptions - CE | Technology | Reference year | Project lifetime | Discount rate | Battery size | fixed OPEX | Round trip efficiency | Variable energy costs CE | Depth of Discharge - DoD | Battery energy capacity degradation over 15 years - CE | Final battery investment overdimesioning (including DoD + degradation) - CE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | year | years | % | MW | €/MW/Y | % | €/MW(h) | % | % | % |
| Parameter value - Tmin LER 15 mins | Li-ion Battery | 2025 | 15 | 4.0% | 30 | 1718 | 86.0% | 0.62 | 90.0% | 23.0% | 44% |
| Parameter value - Tmin LER 20 mins | Li-ion Battery | 2025 | 15 | 4.0% | 30 | 1923 | 86.0% | 0.62 | 90.0% | 21.0% | 41% |
| Parameter value - Tmin LER 25 mins | Li-ion Battery | 2025 | 15 | 4.0% | 30 | 2132 | 86.0% | 0.62 | 90.0% | 20.0% | 39% |
| Parameter value - Tmin LER 30 mins | Li-ion Battery | 2025 | 15 | 4.0% | 30 | 2336 | 86.0% | 0.62 | 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 | 468 |
| Tmin LER 20 mins | 0.67 | 0.94 | 508 |
| Tmin LER 25 mins | 0.83 | 1.16 | 548 |
| Tmin LER 30 mins | 1.00 | 1.37 | 587 |

- Variable energy costs are related to the energy needed to compensate for round-trip losses (86% round-trip efficiency is assumed).
- For volumes and costs, the calculation has been based on average historical frequency profiles and on average DAM prices Nov22-Oct23

**3 Existing LER FCR cost= fixed O&M + variable cost**

| | €/MW(h) |
|---|---|
| Parameter value - Tmin LER 15 mins | 0.82 |
| Parameter value - Tmin LER 20 mins | 0.84 |
| Parameter value - Tmin LER 25 mins | 0.86 |
| Parameter value - Tmin LER 30 mins | 0.89 |

| 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 | 5.05 | 5.67 |
| Tmin LER 20 mins | 5.49 | 6.11 |
| Tmin LER 25 mins | 5.93 | 6.55 |
| Tmin LER 30 mins | 6.36 | 6.98 |

- For each duration, the specific investment cost of a benchmark unit (in €/MW), and fixed O&M (in €/MW/yr) are distributed among several annuities according to the project lifetime.
- The equivalent annual cost for providing FCR (in €/MW per hour) of a benchmark unit is calculated
- Finally, the total cost in €/MW per hour is calculated including variable energy costs.

# New LER non-specifically commissioned for FCR provision 2

## Rationales for neglecting LER non-specifically commissioned for FCR

**Provision of FCR** is currently considered the **most profitable source of revenue of a battery-based providers of ancillary services** (other services require higher E/P ratios).

**BSP would mostly focus solely on the provision of FCR**, with the provision of **other services** (e.g., secondary or arbitrage on DAM) **playing a very minor role**.

*Even considering the cases where another service has a "spot price" higher than that of FCR:*

- *A portion of the CAPEX should be attributed to other services instead of to FCR (the more other services are provided, the less the FCR costs)*
- *Providing other services instead of FCR reduces the yearly average FCR volumes associated with a certain quantity of pre-qualified FCR (the more other services are provided, the less FCR volume is considered on an annual basis, given a certain amount of pre-qualified capacity)*

*The two described effects roughly compensate each other.*

Other possible **LER which can provide the FCR as a side service** (such as EVs, heat pumps) **are neglected** as well.

Their current **technologies are deemed to be still insufficiently mature for playing a significant role** in terms of volumes in the time horizon we're considering.

**New LER non-specifically commissioned for FCR provision are neglected**

# Existing LER 3

## Costs and Volumes

**Costs?**

- CAPEX
- Degradation costs
- **Fixed OPEX**
- **Variable costs**

- *Investment costs are considered sunk costs for existing installations.*

- *Calculated in the same way of the variable energy + fixed OPEX costs for new LER dedicated to FCR provision for **batteries***
- *Assumed substantially equal to zero for other technologies (e.g., Hydro RoR)*

**Volumes?**

**Based on a survey conducted among TSOs**

The purpose is to define the qualified capacity for FCR provision for both LER (according to their **duration and E/P ratio**) and non-LER (differentiated by technology)

*The survey is currently underway.*

*Please note that survey results are out of the scope of the ongoing consultation.*

# Non-LER Costs

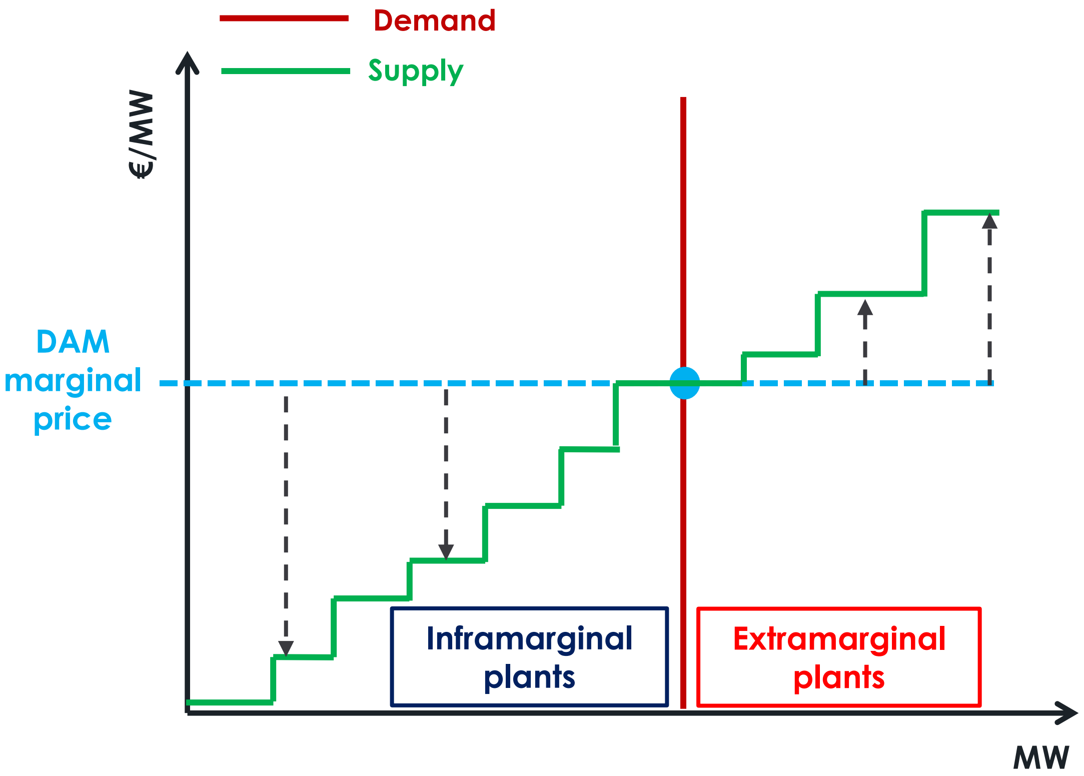
# Non-LER costs

## Opportunity cost for FCR provision

- Conventional FCR providers typically operate both on ancillary services, e.g., FCR, and energy markets.
- Reserved FCR capacity (upward and downward) entails a constraint in terms of power that can be sold on Day Ahead Market

For **non-LER FCR** providers the cost curve definition is based on the **opportunity cost** sustained for reserving FCR capacity, which depends on:

- **DAM marginal price**
- **Production marginal cost,** i.e. offer assuming perfect competition




DAM marginal price > plant marginal cost
**Inframarginal plant**

**FCR cost per MW per hour = DAM marginal Price − Plant marginal cost**

DAM marginal price < plant marginal cost
**Extramarginal plant**

**FCR cost per MW per hour = Plant marginal cost − DAM marginal Price**

# Non-LER costs

## Sources used for the study

**ENTSO-E transparency platform**
- ✓ Historical DAM prices November 2022 – October 2023

**Nordpool**
- ✓ Historical DAM prices November 2022 – October 2023 for France

**World Bank Commodities Price Data (The Pink Sheet), November 2, 2023**
- ✓ Historical Fuel prices (November 2022 – October 2023) for:
  - Coal
  - Brent
  - Natural gas

**US EIA 2022 - ENTSO-E TYNDP24**
- ✓ Nuclear fuel price 2022 (US EIA is the primary source, adopted as reference for TYNDP24 long term scenarios)

**EEX Emissions market / Primary Market Auction**
- ✓ EUA primary auction results November 2022 – October 2023

**ENTSO-E TYNDP20**
- ✓ efficiencies, emissions factors, variable O&M costs
- ✓ available capacity per technology per country for 2025 scenario

**ENTSO-E transparency platform for further data needed for pumped hydro resources**
- ✓ Current (2022-2023) installed pumped-hydro capacity per country
- ✓ Current (2022-2023) actual hourly generation per technology (type) per country

- **All historical spot prices data refer to the same period: Nov 22 – Oct 23**
- **All historical spot prices are from publicly available and referenced sources**

# Non-LER costs

## Volumes

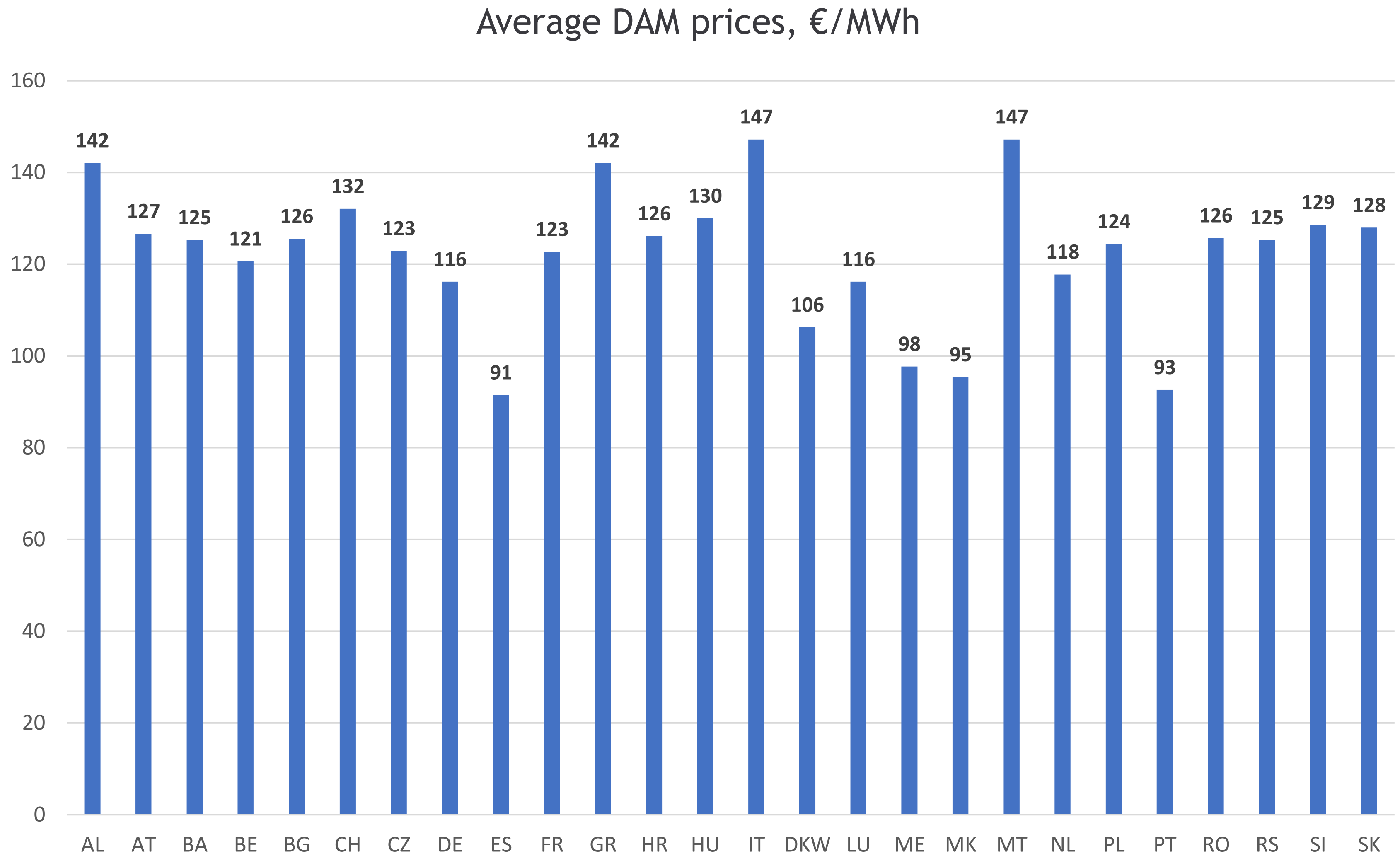
- As for existing LER, **non-LER volumes are derived from the undergoing survey among TSOs**.
- Volumes are **divided by country and by technology** to properly differentiate the FCR cost.
- For country with no available data, pre-qualified capacity in the German tenders for primary control reserve will be used as a proxy of the share of the total capacity per technology that is reserved/used for FCR provision.

# Non-LER costs

## Fuel prices and DAM prices

| Fuel prices | |
|---|---|
| **Technology** | **Fuel price [€/net MWh]** |
| Nuclear | 6.05 |
| Lignite | 6.64 |
| Hard coal | 22.88 |
| Gas | 54.33 |
| Light oil | 65.17 |
| Heavy oil | 45.98 |
| Oil shale | 8.28 |

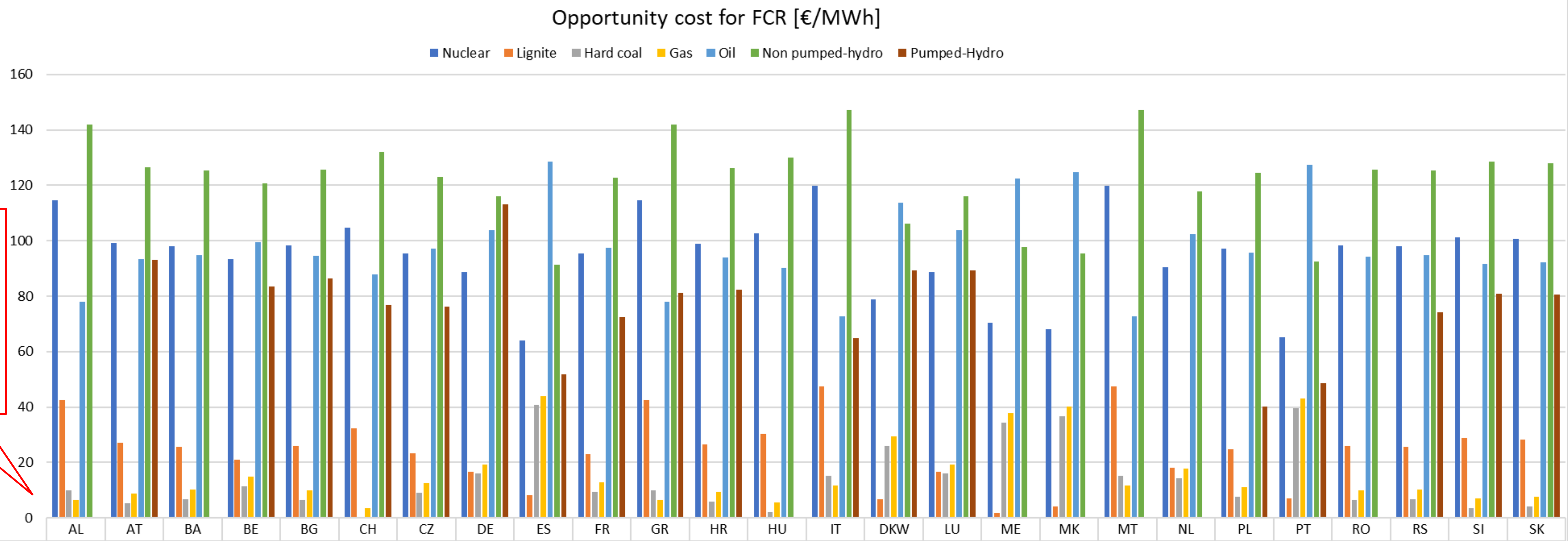
CO2 price EU ETS:
84.5 €/tCO2



# Non-LER costs

## Opportunity cost results

- **New LER 5.7÷7.0 €/MWh**
- **Existing LER 0.82÷0.89 €/MWh**




| | AL | AT | BA | BE | BG | CH | CZ | DE | ES | FR | GR | HR | HU | IT | DKW | LU | ME | MK | MT | NL | PL | PT | RO | RS | SI | SK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclear | 115 | 99 | 98 | 93 | 98 | 105 | 96 | 89 | 64 | 95 | 115 | 99 | 103 | 120 | 79 | 89 | 70 | 68 | 120 | 90 | 97 | 65 | 98 | 98 | 101 | 101 |
| Lignite | 42 | 27 | 26 | 21 | 26 | 32 | 23 | 17 | 8 | 23 | 42 | 27 | 30 | 48 | 7 | 17 | 2 | 4 | 48 | 18 | 25 | 7 | 26 | 26 | 29 | 28 |
| Hard coal | 10 | 5 | 7 | 11 | 7 | 0 | 9 | 16 | 41 | 9 | 10 | 6 | 2 | 15 | 26 | 16 | 34 | 37 | 15 | 14 | 8 | 39 | 6 | 7 | 4 | 4 |
| Gas | 6 | 9 | 10 | 15 | 10 | 3 | 13 | 19 | 44 | 13 | 6 | 9 | 6 | 12 | 29 | 19 | 38 | 40 | 12 | 18 | 11 | 43 | 10 | 10 | 7 | 8 |
| Oil | 78 | 93 | 95 | 99 | 95 | 88 | 97 | 104 | 129 | 97 | 78 | 94 | 90 | 73 | 114 | 104 | 122 | 125 | 73 | 102 | 96 | 127 | 94 | 95 | 91 | 92 |
| Non pumped-hydro | 142 | 127 | 125 | 121 | 126 | 132 | 123 | 116 | 91 | 123 | 142 | 126 | 130 | 147 | 106 | 116 | 98 | 95 | 147 | 118 | 124 | 93 | 126 | 125 | 129 | 128 |
| Pumped-Hydro | | 93 | | 83 | 86 | 77 | 76 | 113 | 52 | 73 | 81 | 82 | | 65 | 89 | 89 | | | | | 40 | 49 | | 74 | 81 | 80 |

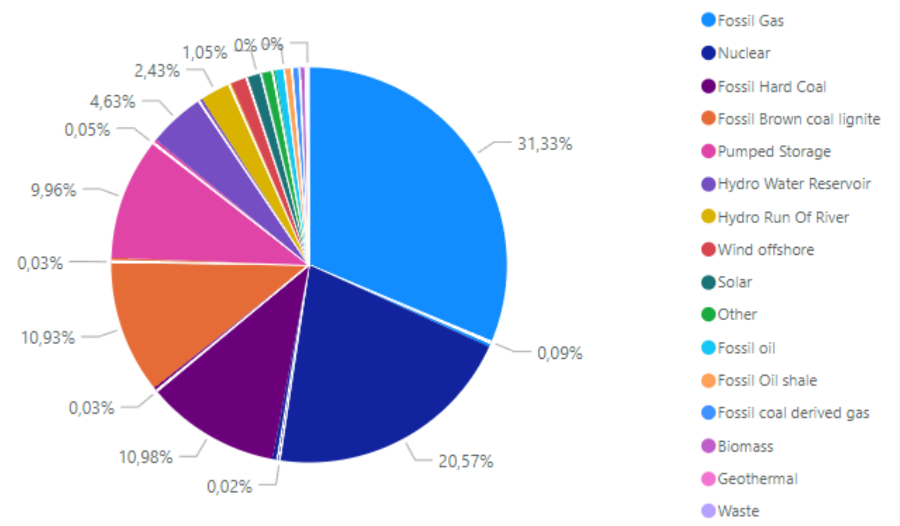
# Technical input

# Update of technical data - Outages

## Outages on generation units – considered plants

The set of plants whose outages are considered is derived from the Transparency Platform. Only **units greater than 100 MW** are considered. Adopting **2025 as target year**, it results a total of **1253 units**.

| Technology | Installed capacity GU [MW] | Number of GU | Average size [MW] | Maximum size [MW] |
|---|---|---|---|---|
| Fossil Gas | 136921 | 389 | 352 | 1304 |
| Nuclear | 89898 | 104 | 864 | 1675 |
| Fossil Hard Coal | 47975 | 135 | 355 | 1075 |
| Fossil Brown coal lignite | 47754 | 147 | 325 | 1058 |
| Pumped Storage | 43518 | 202 | 215 | 1307 |
| Hydro Water Reservoir | 20222 | 113 | 179 | 1254 |
| Hydro Run Of River | 10625 | 56 | 190 | 737 |
| Wind offshore | 5605 | 23 | 244 | 407 |
| Solar | 4597 | 23 | 200 | 430 |
| Other | 3488 | 14 | 249 | 849 |
| Fossil oil | 3111 | 19 | 164 | 288 |
| Fossil Oil shale | 2251 | 13 | 173 | 270 |
| Fossil coal derived gas | 2228 | 8 | 279 | 450 |
| Biomass | 1394 | 5 | 279 | 392 |
| Geothermal | 114 | 1 | 114 | 114 |
| Waste | 109 | 1 | 109 | 109 |




entsoe Transparency Platform

*Filter applied to data*:

- **GU Status** = “Commissioned”
- **GU Installed Capacity** ≥ 100 MW
- **GU Installed Capacity** ≠ “”
- **Production Type** = All but “Wind Onshore”
- **Validity**: 01/01/2025 - 31/12/2025
- Countries: CE SA + EST + LV + LT (UA/MD, BZ SARD Excluded)

*Further rules applied to data*:

- If **GU Status = “” -> PU Status** is considered

**Wind onshore units are not considered** since their most likely outages don’t result in the complete and sudden loss of their injection at the PoC.

**For nuclear and coal plants “partial outages” are also considered** (events with a sudden but partial loss of power output, without total disconnection).

A total of 394 partial outages are considered.

Probability of occurrence and power loss are derived from TP data (“Unavailability of Production and generation Units”)

**Outages on load side are not considered** (negligible impact in terms of power imbalance at SA level).

# Update of technical data - Outages

## Outages on generation units – Power loss associated with outages

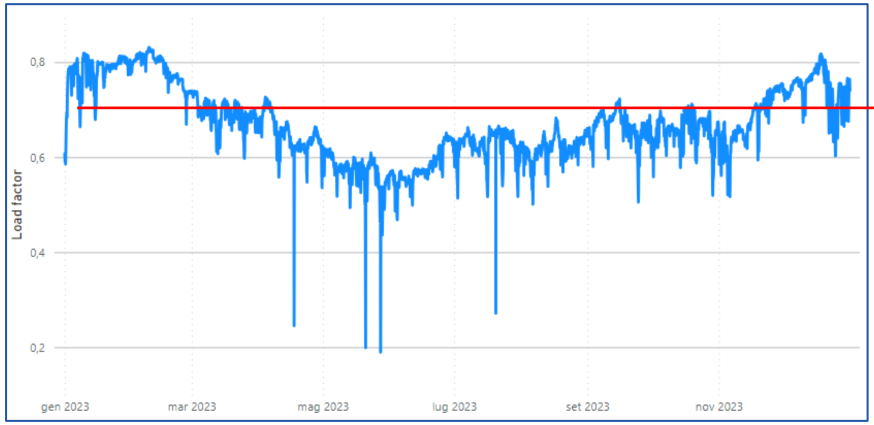
When an outage on a production unit occurs, the power imbalance caused to the system is calculated considering the installed power and a load factor differentiated for technology:

$$P = P_{inst} \cdot Load\ Factor$$

Where:

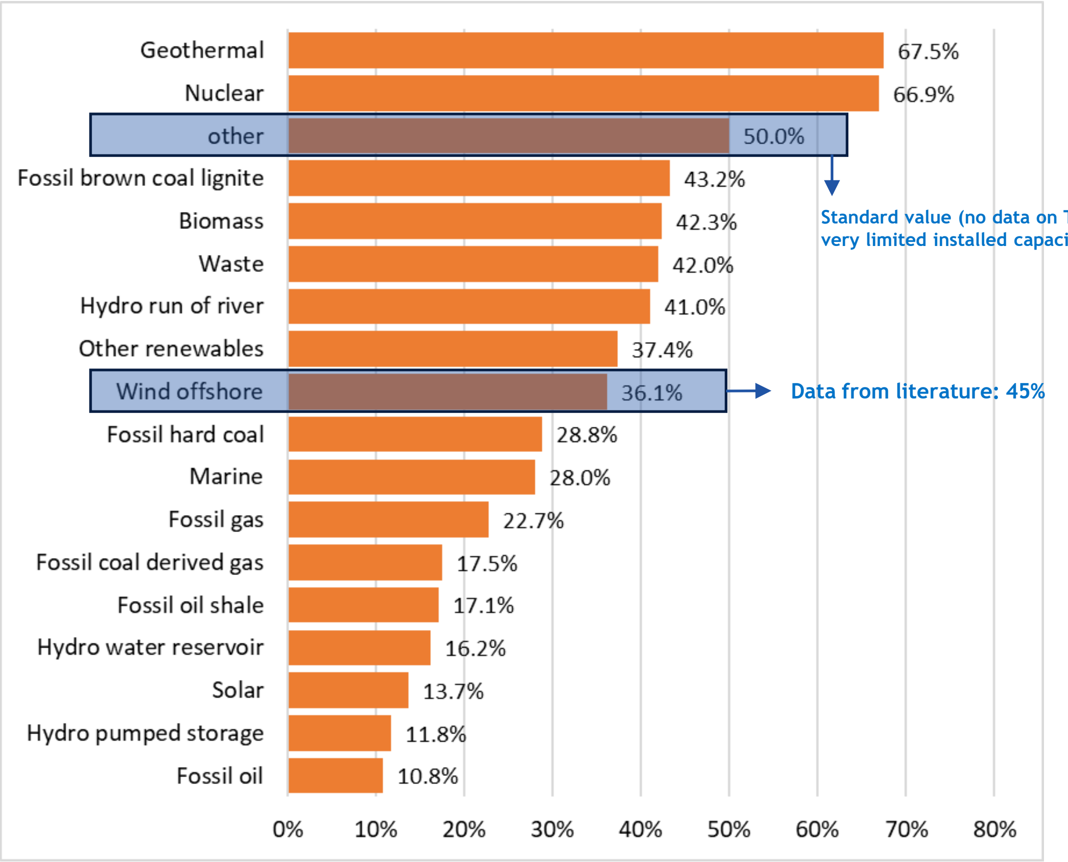
$P_{inst}$: Installed power on the Generation Unit as derived from TP Table "Installed Capacity Per Production Type"

$$Load\ Factor = \frac{\sum_{h=1}^{h=8760}(Actual\ Generation\ per\ Production\ Type)_{h,i}}{(Installed\ Capacity\ per\ Production\ Type)_i},\ \forall\ technology\ i$$




E.g., 90.9 GW of nuclear units were installed in 2023 (w/o 100 MW threshold).
The average LF is **66.9%**.

*Nuclear LF hourly trend (**from 2023 TP data**)*




*Adopted Load Factors for each technology (**from 2023 TP data**)*

# Update of technical data - Outages

## Outages on generation units – Probability of occurrence

To each outage shall be associated a probability of occurrence. This probability is exploited by the probabilistic model to randomly extract an outage with the correct rate.

The failure rates for outages on thermoelectric units are derived from literature[1]. Hydroelectric units' failure rate is assumed equal to gas turbine.

| | Fossil-fired | | | Combined Cycle | Gas Turbine | Nuclear |
|---|---|---|---|---|---|---|
| | 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 | | | | | |

For offshore wind:

- Failure rate is derived from literature. It's calculated only for the connection from wind farm to the shore.

  An average value of **0.005 failure/km/year** is assumed. An average distance of **75 km** is assumed between the wind farm and the connection point on the shore.

- Load factor is assumed to be 0.45.

  Source: "FUTURE OF WIND - Deployment, investment, technology, grid integration and socio-economic aspects.", IRENA 2019.

[1] *Analysis of Unavailability of Power Plants 2008 - 2017» VGB report for hydroelectric and thermoelectric technologies.*

# Update of technical data - Outages

## Outages on HVDC – Power loss

The list of HVDCs in service in 2025 is updated:

- 23 connections (connecting CE SA with other SAs., Baltic states included).
- Power loss based on historical flows (TP for the year 2023).

  The direction and the power lost if an outage occur depends on the date/time of outage.

  Viking link and COMETA historical data are not available, TYNDP 2030 flows are considered.

| Name | Power [MW] | Zone From | Zone To | Status |
|---|---|---|---|---|
| IFA 1 | 2000 | FR00 | UK00 | In service |
| BritNed | 1000 | NL00 | UK00 | In service |
| NorNed | 700 | NL00 | NOS0 | In service |
| Skagerrak 1_2 | 250 | DKW1 | NOS0 | In service |
| Skagerrak 3 | 1000 | DKW1 | NOS0 | In service |
| Skagerrak 4 | 700 | DKW1 | NOS0 | In service |
| Konti-Skan 1 | 250 | DKW1 | SE03 | In service |
| Konti-Skan 2 | 300 | DKW1 | SE03 | In service |
| StoreBaelt | -600 | DKE1 | DKW1 | In service |
| Kontek | 600 | DE00 | DKE1 | In service |
| Baltic Cable | 600 | DE00 | SE04 | In service |
| SwePol | 600 | PL00 | SE04 | In service |
| Nemo | 1000 | BE00 | UK00 | In service |
| NordBalt | 700 | LT00 | SE04 | In service |
| Estlink 1 | 350 | EE00 | FI00 | In service |
| Estlink 2 | 650 | EE00 | FI00 | In service |
| IFA 2 | 1000 | FR00 | UK00 | In service |
| ElecLink | 1000 | FR00 | UK00 | In service |
| Viking Link | 1400 | DKW1 | UK00 | In service |
| Kriegers Flak CGS | 400 | DE00 | DKE1 | In service |
| NordLink | 1400 | DE00 | NOS0 | In service |
| COMETA | -400 | XMA00 | ES00 | In service |
| SAPEI | 1000 | ITCS | ITSA | In service |

| *Colour legend* |
|---|
| Connections to UK or IE |
| Connections to Nordic |
| Connections to Nordic (from Baltic states) |
| Connections to other non-synch. areas |

$$P_{Loss,h} = min\left(max\left(0.5 * P_{HVDC}, \left|Flow_{h,A\leftrightarrow B}\right| / n_{interconn,A\leftrightarrow B}\right), P_{HVDC}\right)$$

Where:

$P_{HVDC}$ is the nominal power of the HVDC;

$Flow_{h,A\leftrightarrow B}$ is the flow in the hour h between the area A and area B;

$n_{interconn,A\leftrightarrow B}$ is the number of HVDC connecting area A and area B:

if data historical flow data are available for the single HVDC, this parameter is equal to one).

if data historical data are available only for the inter-area flows this parameter is equal to the number of HVDCs connecting the two areas.

# Update of technical data - Outages

## Outages on HVDC – Probability of occurrence

Failure rate based on literature ("ENTSO-E HVDC Utilization and Unavailability Statistics 2020", 24 June 2021.)

**2012-2020 statistics for Baltic/Nordic HVDCs** are used as reference. On average, **3.5 outages/year** occur.

If a connection is present in the ENTSO-e report, its outage/year statistic is used as failure rate.

If a connection is not present in the ENTSO-e report, the average outage/year statistic is used as failure rate.

Data from «ENTSO-E HVDC Utilization and Unavailability Statistics 2020»

| HVDC | outage/year |
|---|---|
| Baltic cable | 3.67 |
| Cobra cable | 2.00 |
| Estlink 1 | 5.78 |
| Estlink 2 | 3.29 |
| Fenno-Skan 1 | 5.22 |
| Fenno-Skan 2 | 3.78 |
| Kontek | 1.22 |
| Konti-Skan 1 | 5.44 |
| Konti-Skan 2 | 6.22 |
| LitPol link | 2.40 |
| NordBalt | 6.40 |
| NorNed | 3.11 |
| Skagerrak 1 | 2.33 |
| Skagerrak 2 | 1.89 |
| Skagerrak 3 | 2.33 |
| Skagerrak 4 | 3.50 |
| StoreBaelt | 1.22 |
| SwePol | 4.67 |
| Vyborg link | 1.67 |
| NordBalt | 6.40 |
| Estlink 1 | 5.78 |
| Estlink 2 | 3.29 |
| ***Average*** | ***3.71*** |

Input failure rate

| HVDC | Failure rate [event/year] |
|---|---|
| IFA 1 | 3.71 |
| BritNed | 3.71 |
| NorNed | 3.11 |
| Skagerrak 1_2 | 3.71 |
| Skagerrak 3 | 2.33 |
| Skagerrak 4 | 3.50 |
| Konti-Skan 1 | 5.44 |
| Konti-Skan 2 | 3.71 |
| StoreBaelt | 1.22 |
| Kontek | 1.22 |
| Baltic Cable | 3.67 |
| SwePol | 4.67 |
| Nemo | 3.71 |
| NordBalt | 6.40 |
| Estlink 1 | 5.78 |
| Estlink 2 | 3.29 |
| IFA 2 | 3.71 |
| ElecLink | 3.71 |
| Viking Link | 3.71 |
| Kriegers Flak CGS | 3.71 |
| NordLink | 3.71 |
| COMETA | 3.71 |
| SAPEI | 3.71 |

# Update of technical data - Frequency

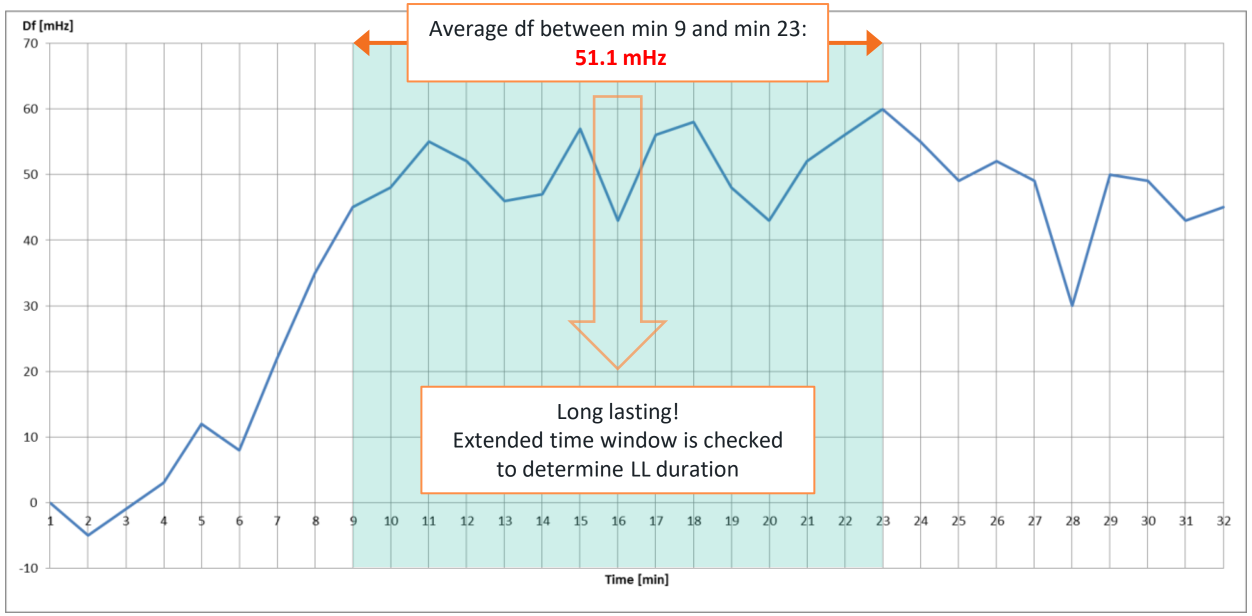
## Choice of years to be used as frequency dataset

CBA methodology relies on the use of historical frequency records to derive statistics about DFDs and LLEFDs.

**LLEFDs** (Long-Lasting Extraordinary Frequency Deviations) are **events with an average steady state frequency deviation larger than ±50 mHz over more than 15 minutes**. LLFDs play an important role in the CBA results.

The **choice on historical frequency dataset** shall consider **<u>two contrasting needs</u>**:

- the selected period should be **<u>representative</u>** of the system in years to come (very old frequency data could be misleading).
- dataset should be **<u>long enough</u>** to represent a significant input for the probabilistic model used in the CBA (several years of data are required to get reliable results).




*Example of identification of a long-lasting extraordinary frequency deviations*

# Update of technical data - Frequency

## Choice of years to be used as frequency dataset

To address both needs, TSOs have **considered the possibility to apply retroactive manipulations on older historical frequency data** to make their frequency phenomena similar to those experienced by CE SA in the more recent years.

With regard to LLEFDs, less recent events would have been manipulated (amplitude/duration) to make them resemble those occurred more recently.

However, **such retroactive manipulation of historical frequency data it is not endorsed by TSOs**:

- **every manipulation** of historical frequency data is **intrinsically an arbitrary operation**. A frequency event result from the combination of multiple, concurrent factors. To modify the trend of a specific event means to deterministically suppose that - given the same combination of factors - the system would react today in a different way as it did in the past.
- the **last couple of years don't show an improvement in terms of number and energetic content of LLEFDs**. The events recorded in 2022-2023 resemble (in amplitude, duration and frequency of occurrence) those occurred roughly ten years ago. In this sense the last two years present worse conditions when compared to the latter half of the 2010s. Such worsening can be traced back to the rapid evolution the CE system is experiencing in terms of energy mix. The worsening took place notwithstanding the mitigation measures put in place by TSOs.

CE TSOs consider the **use of the last 10 years (2014-2023) the best compromise** between having a significant amount of historical data and, at the same time, having a frequency behavior that is representative of the present and coming years.

From the historical frequency dataset used as input of the CBA are excluded the events in which emergency state is triggered (e.g., separation of the CE power system on 8 January 2021).

# Backup

# Schedule of activities in 2023-2024