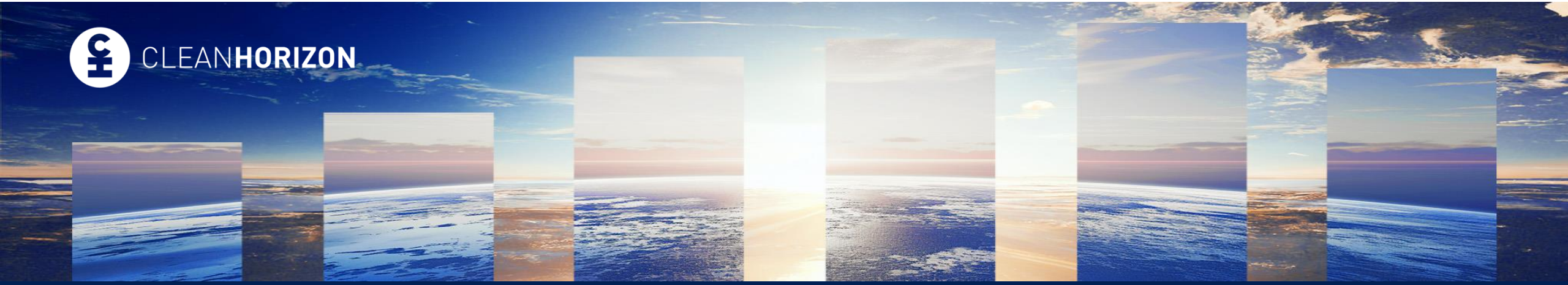

Grid Connection Limitations and Their Impacts on BESS Development

March 12th 2025

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SOLUTIONS

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STORAGE INDEX

15 YEARS OF EXPERTISE IN ENERGY STORAGE

Agenda

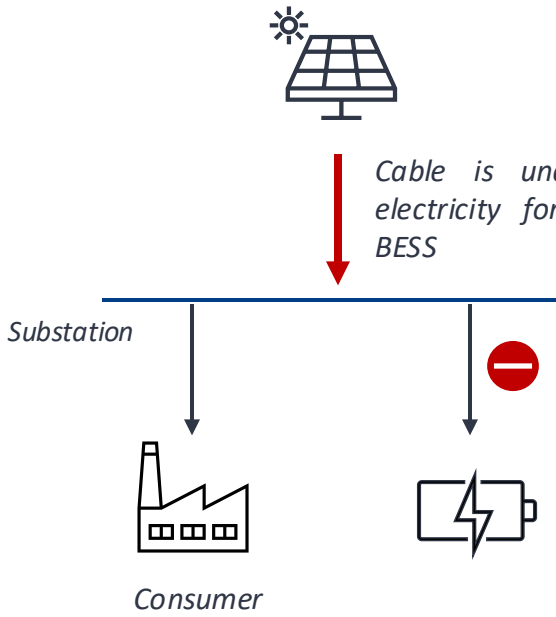
1. WHAT ARE GRID LIMITATIONS?
2. MODELING AND ASSESSING THE IMPACT OF GRID LIMITATIONS ON BESS REVENUES
3. STRATEGIES TO ADRESS LIMITATIONS IN PROJECT DEVELOPMENT

What are grid limitations?

Grid limitations are due to the under sizing of the network infrastructure, which cannot support the asset's full-power operation at all times. They result in constraints on the power than can be either injected or withdrawn by the assets during certain periods of the year.

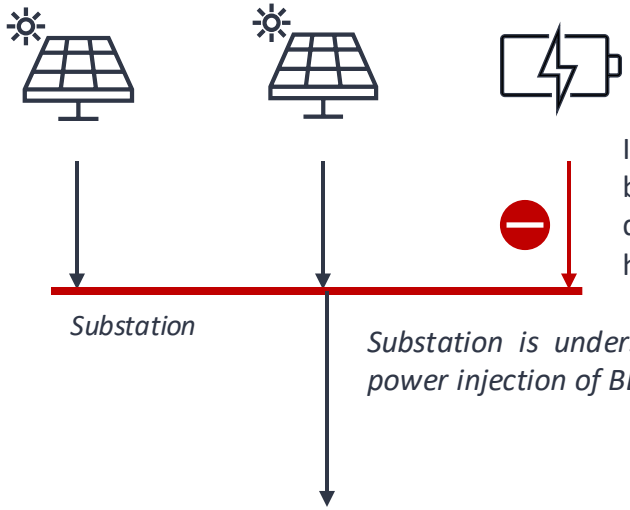
In order to optimize the use of the current grid, the TSO can impose grid limitations clauses on new powerplants such as storage, giving priority to renewable power.

Constraint on the cables:



In this case, the BESS might be **constrained on consumption** during peak consumption hours of the consumer.

Constraint on the substation:



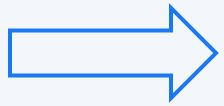
In this case, the BESS might be **constrained on injection** during peak PV injection hours.

When do TSO impose grid limitations?

To ensure grid security and maintain the quality of power supply, TSOs can impose grid limitations on producers in either of the following scenarios:

Early connection date: When a production plant is constructed and connected to the grid before the completion of reinforcement work specified in the connection agreement, these works may limit the plant's injection capacity.

The depth of power limitation could be partial or total, depending on the grid's capacity and constraints at the time.



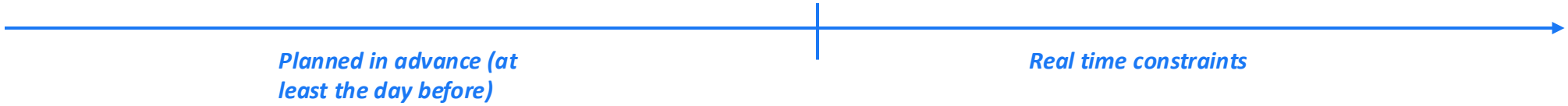
Permanent Grid Constraints: When the connection of a production plant is subject to permanent constraints on the grid, it may require non-continuous grid limitations to manage grid stability.

What are the main types of grid limitations?

Grid limitations can be classified into two main types:

Preventive grid limitations : Applied if it is not possible to guarantee that disturbances can be controlled within a specific timeframe or if the required actions exceed the allowable limit set by the TSO. In this case, as part of a preventive strategy, TSO can install automatic devices dedicated to isolating the plant from the grid to prevent potential accidents.

Curative grid limitations : Grid limitations which have not been planned the day before and which happen in real time or close to real time.



Preventive grid limitations will result in a reoptimisation of the asset operation on the markets.

Curative grid limitations which prevent the asset to provide ancillary services last minute can result in high penalties for non-provision of ancillary services and require back up to minimise this impact.

Grid limitations are becoming the norm in Europe

Grid limitations for storage assets are becoming the norm in European countries.

With increasing amounts of grid connection requests for storage and fast renewable deployment, TSOs apply grid limitations to storage to ensure priority for renewables.

Grid limitations affect energy storage projects in most European countries

Preventive limitations:

- Max number of hours of potential grid limitations
- The maximum depth of power limitations in MW,

Curative limitations:

- The risk duration over a rolling period of five (5) years, from the date of first coupling of the Plant, distinguishing between different climatic regimes,
- The maximum depth of power limitations in MW,
- As an indication, an expected evaluation of limitation hours over a rolling period of five (5) years

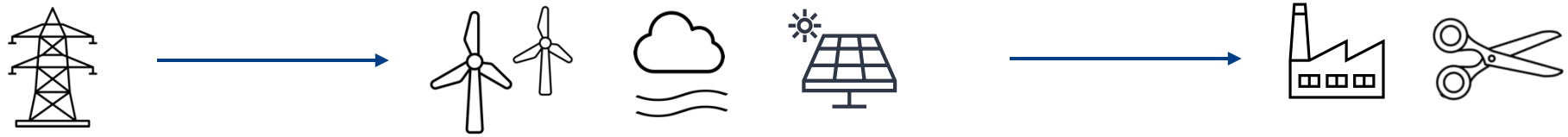
% of the time where the asset grid connection can be limited

% of the time where the asset grid connection can be limited

TSO tend to be conservative and therefore the limitations provided on the grid connection agreements are the worst case.

It is possible to estimate the real number of limitations using algorithm that takes into account grid infrastructure, neighbouring generation and consumption

Using public data, a realistic case of grid limitations can be estimated



Current and future status of electrical infrastructure (cables, substations)

With climatic scenarios and expected renewable production, a future production profile can be calculated

Using local consumption profile as well as curtailment objectives of the TSO, grid limitations can be estimated

- This methodology assumes that grid limitations are applied when the production-consumption power gap (in MW) exceeds a certain level. It searches for this level and calculates the corresponding curtailed energy and hours which should match the expected curtailed energy announced by TSO.
- Using this method, the algorithm generates a list of power limitations depth on all the region for each 15-minute time step, along with the curtailed energy for each period.
- **Using such algorithm enables to understand what is a realistic scenario of grid limitations for a given grid connection agreement.**

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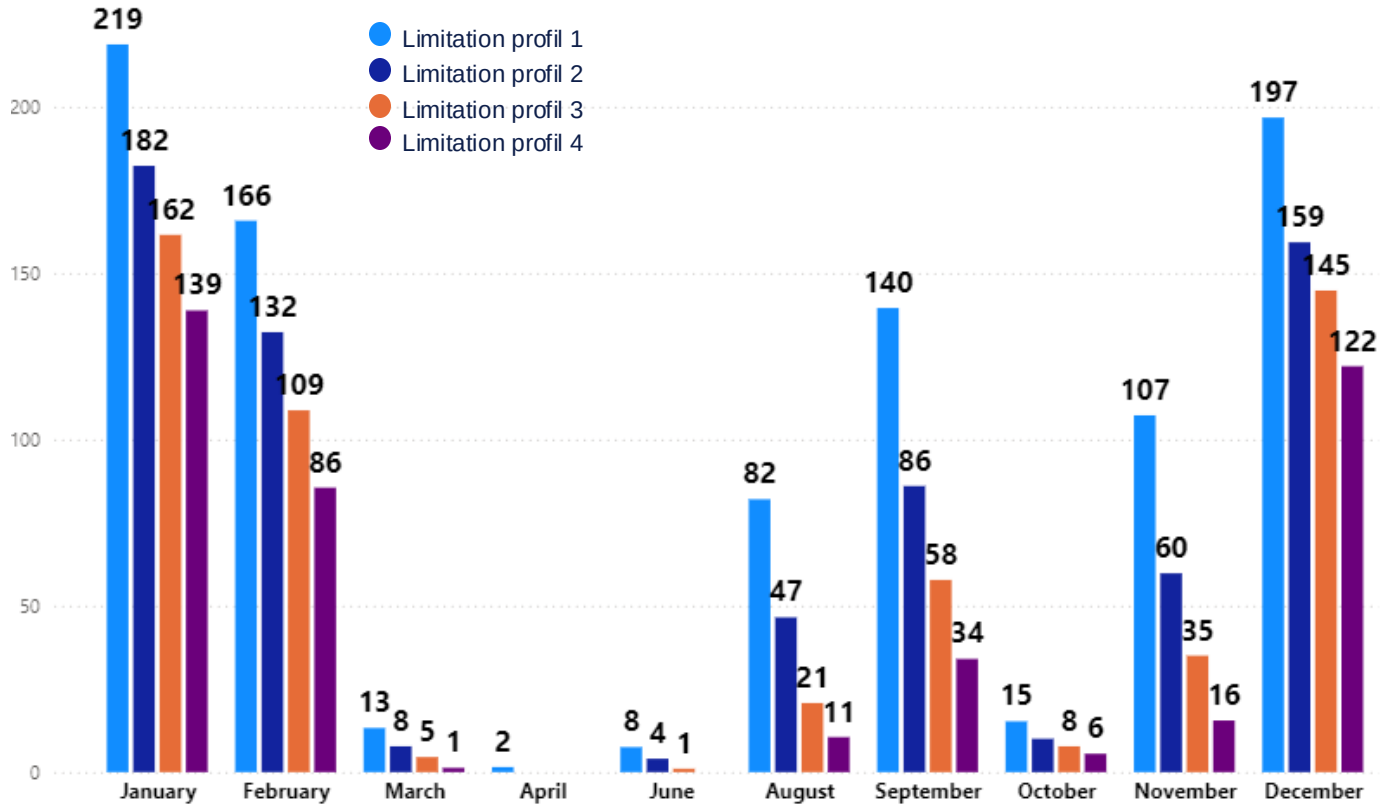
The projected limitation hours could significantly affect project profitability, a realistic analysis is essential before assessing project viability

Estimation and distribution of the number of limitation hours



- TSOs often **overestimate** the grid limitations.
- A more **detailed analysis** should be considered for project revenues.

Simulation tool for project sizing, performance analysis and optimisation

COSMOS BY CLEAN HORIZON

Clean Horizon optimizes the economic model, based on the quantitative factors

ECONOMIC PARAMETERS

Storage / PV/ WIND CAPEX
Storage / PV/ WIND OPEX

TECHNICAL PARAMETERS

MW of storage
MWh of storage
MWp of PV
MW of WIND
MW of grid connection
Grid limitation profile

MARKET PARAMETERS

Forecast of ancillary service prices
Forecast of wholesale prices
Forecast of balancing mechanism prices

This tool allows

1

To determine optimal sizing for different configurations of the storage system

2

To calculate the cashflows, NPV and IRR

3

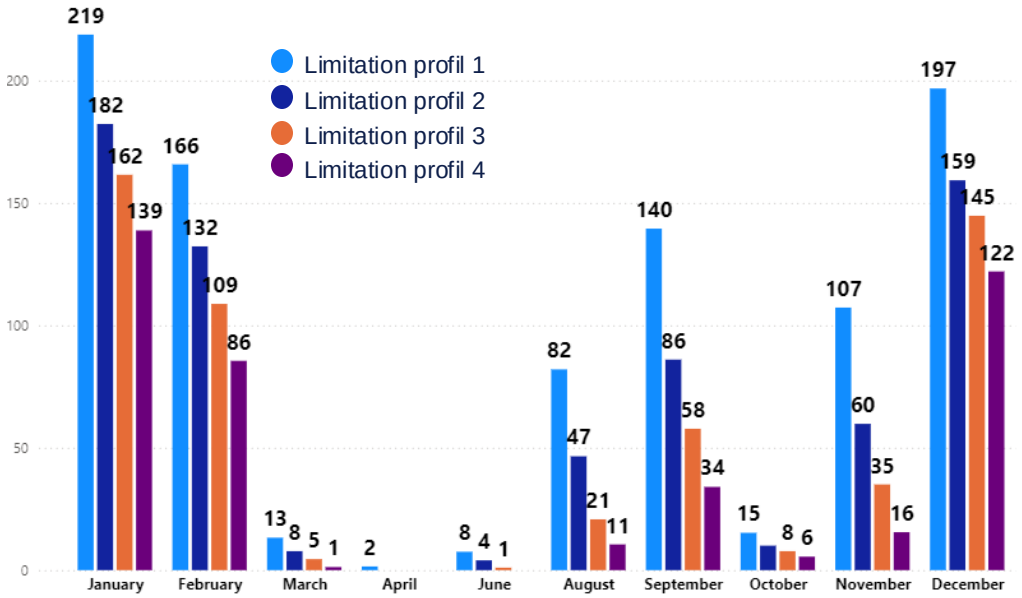
Generate sensitivity analyses including multiple limitations profiles

4

While optimising dispatch and swaping positions based on limitation profiles

COSMOS accurately evaluates the operational performance and profitability of energy storage systems under such constraints

Estimation and distribution of the number of limitation hours

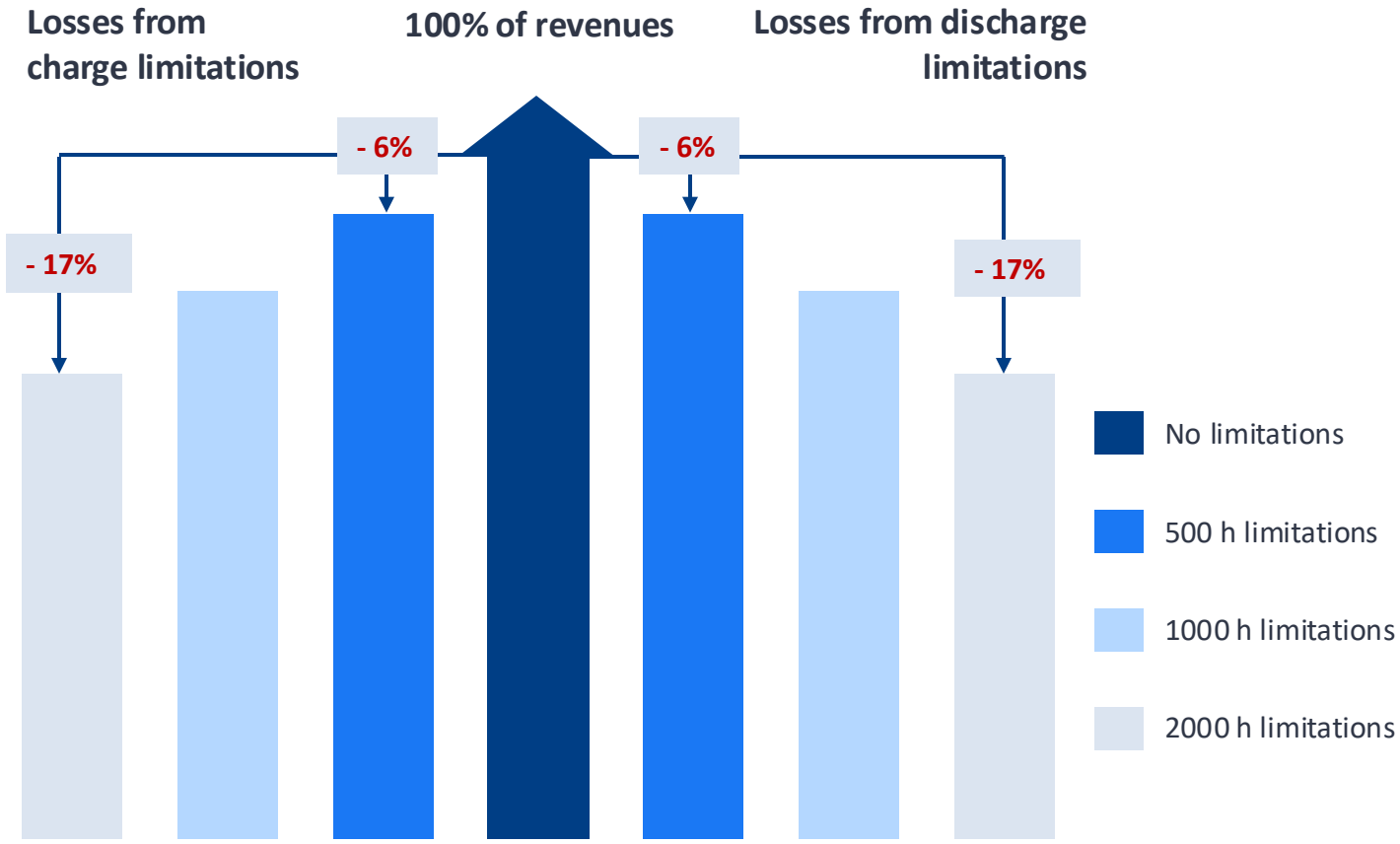


Results of simulations

Grid limitation profile	Project IRR (%)
Without limitations	13.9%
Profile 4	13.2%
Profile 3	12.8%
Profile 2	12.5%
Profile 1	11.5 %

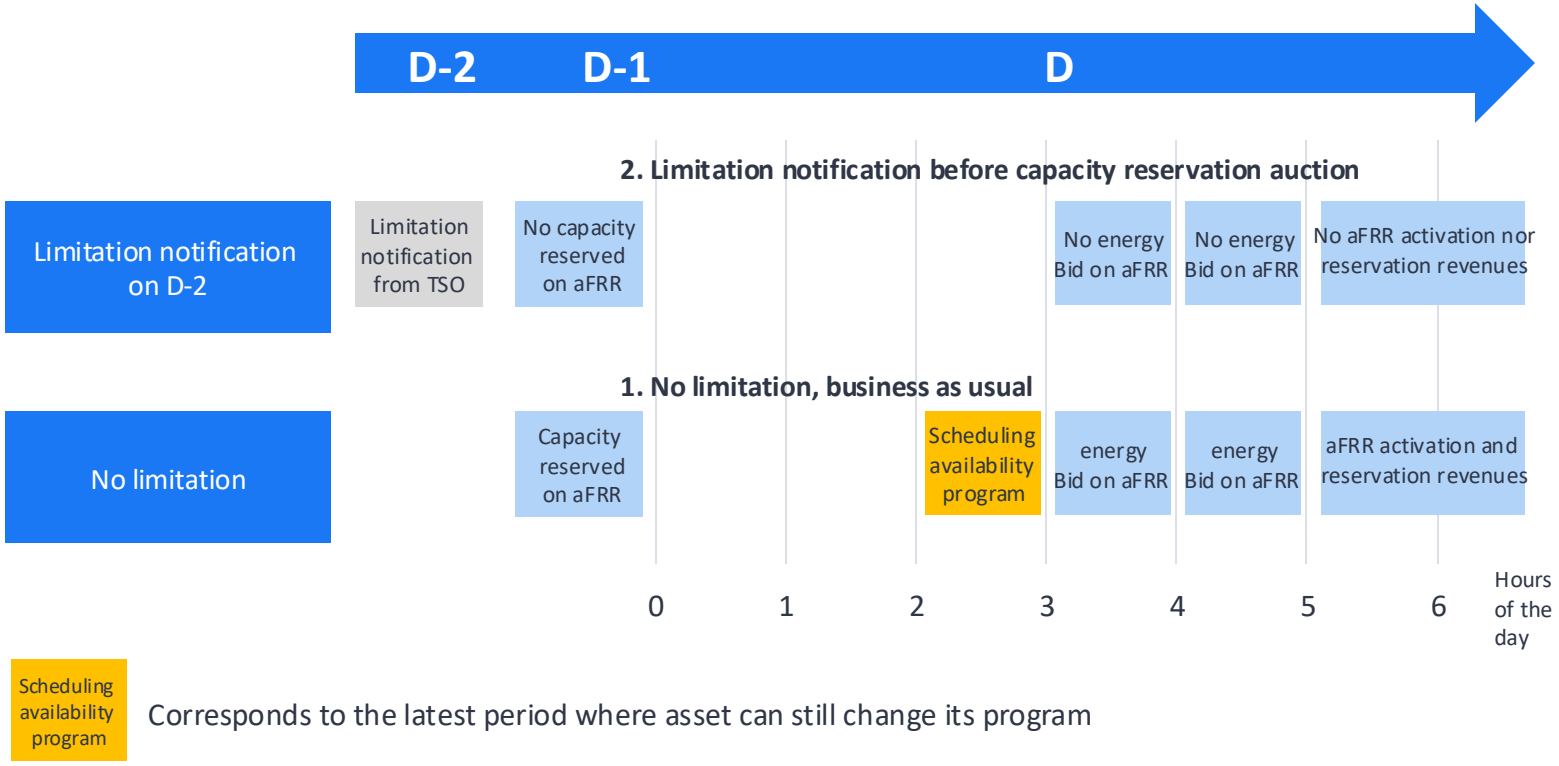
Both charge and discharge limitations can have a significant impact on overall revenue losses

- A random limitation profile has been considered to evaluate the impact of Charge Vs Discharge preventive limitations using COSMOS.
- The simulation has been done within a year where ancillary services are the most dominant revenue source for the project. Therefor, the revenue loss is related to both capacity and energy revenues.
- Revenue decreases between **6%** and **17%** depending on the number of limitation hours, ranging from **500** to **2000** hours for both charge **or** discharge limitations.
- If the BESS is restricted in charge **and** discharge, it doesn't double the revenue loss but still they increase even further as it ranges between **7%** and **22%**



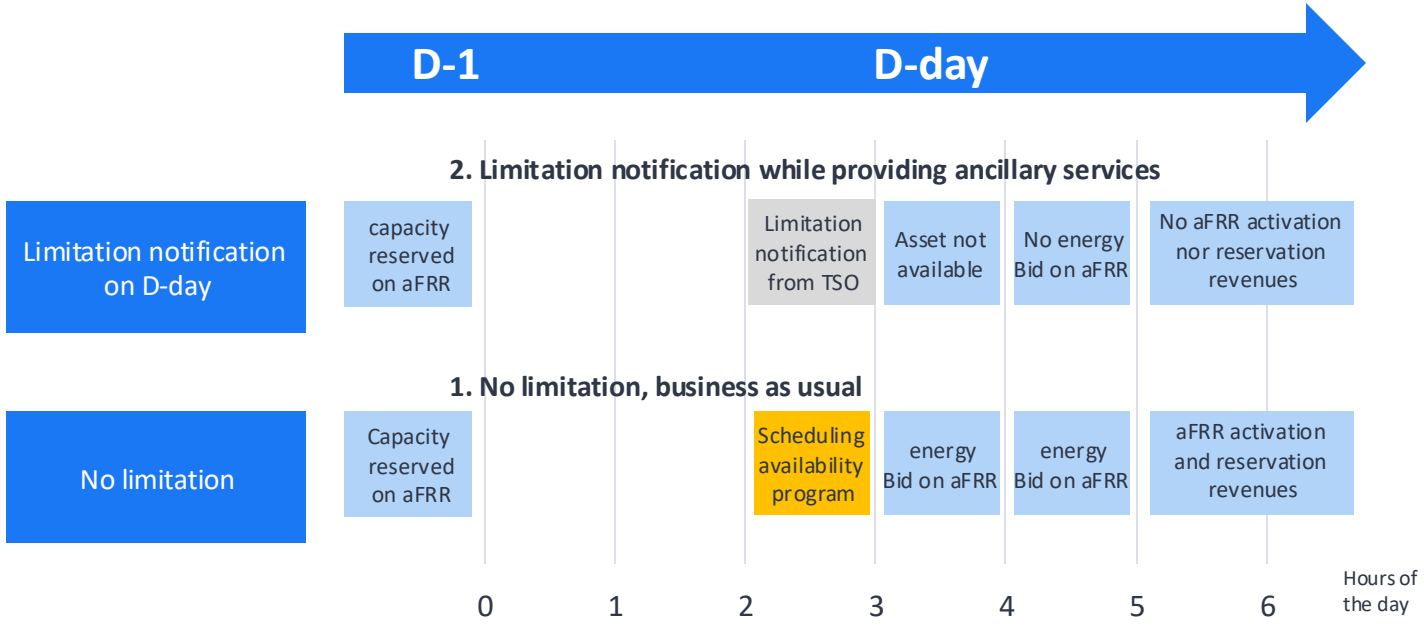
BESS will not face penalties when subject to grid limitations, provided that notification is given two days in advance

- The timing of grid limitation notifications is critical in determining the extent of revenue losses for BESS participating in ancillary services and in avoiding penalties.
- If the asset receives notification of the grid limitations at least two days prior, no risk of penalties is expected.



There is a high potential risk of penalties for asset owners losing grid access without backup while providing ancillary services

- According to the French TSO's rules for ancillary services participation, penalties can be significant if the asset owner has committed to providing services for the upcoming hour and then loses grid access. Without a backup asset, this situation could become very costly.



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BESS optimization strategies need to be adapted to the new paradigm

- **BESS projects subject to limitations might to shift their operation to less lucrative but more flexible services**
    - For instance, ancillary services (FCR, aFRR) often require day ahead lock of a position, which might be impossible to hold due to limitation
    - Alternatively, positions on intraday and balancing markets can be changed much closer to real time, with limited consequences on the revenues

- **Forecast of grid conditions will be required to be able to optimize**
    - With more data, local situations of a given grid can be anticipated
        - In a solar region – limitations will likely occur during sunny day hours
        - In a wind region – limitations will occur during windy periods
        - In a consumption region – limitations will occur during hours of peak demand
    - Availability of information from TSO will be key -> there still a lot of work to be done on that aspect

In the next few years, knowledge of market conditions will not be sufficient to optimize a BESS – knowledge of local grid conditions will probably be a key deifferentiating factor for optimizers

Route-to-market agreements need to consider limitations in a project-friendly manner

- Given that grid limitations can impact the revenues in an uncertain way, route-to-markets offering guaranteed revenues want to protect themselves against the risk of grid limitations. Therefore, the level of floor or tolling agreeable is reduced.
    - One position from the aggregators is to consider that the floor will be reduced to the pro rata of the maximum reduction of revenues limitation can create on a project
    - Another position is to base floor revenues on a low-risk market strategy (e.g day ahead and intraday trading only), such that as long as the limitations are correlated with the market conditions (which is often the case), the limitations have little impact on revenues.

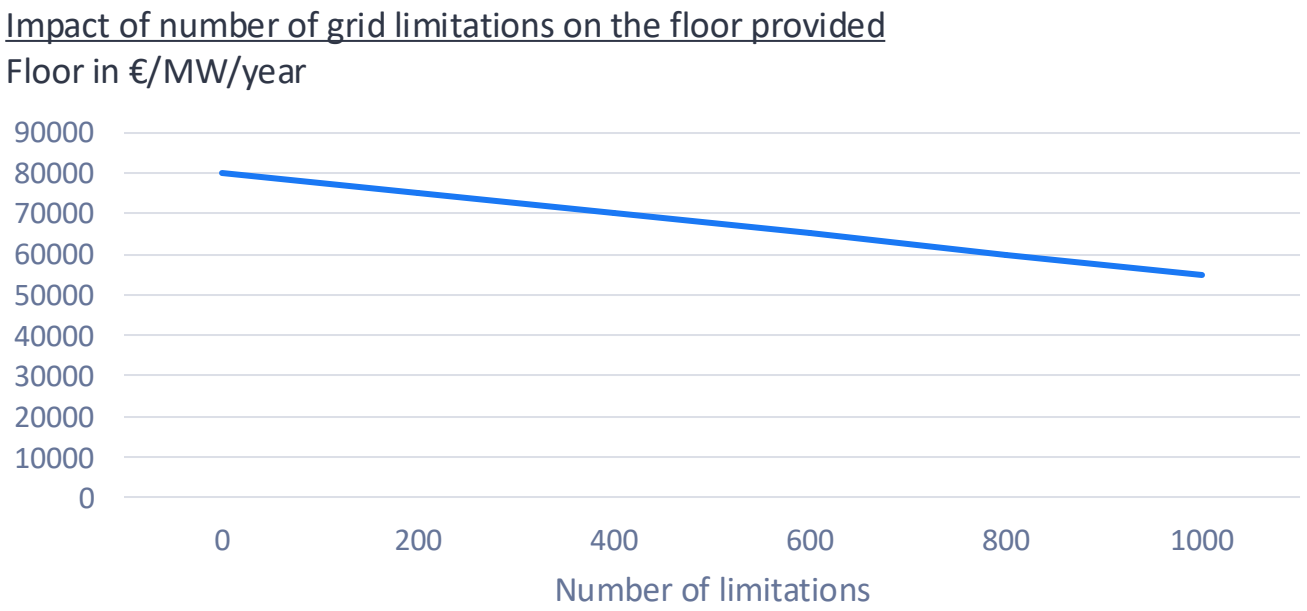
Given the uncertain nature of limitation, new types of remunerations arise

Without limitations, route to market propose floor or tolling contracts with no condition of provision.

With limitations, to reduce their exposure to grid limitations, route to market can propose contracts where the floor or tolling value is adjusted ex-post based on the number of effective grid limitations and their depth and nature.

Depending on the route to market strategy on the market, the impact of limitations can be high, for example, impact of curative grid limitations on ancillary services revenues will be higher as it will lead to penalties, whereas trading will be less impacted.

Some route to market propose an insurance against grid limitations where they offer no impact on tolling/floor level if the number of limitations doesn't surpass a certain limit.



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