aFRR model

1 Introduction

The purpose of this document is to explain the functioning of the aFRR (automated Frequency Restoration Reserve) balancing product simulation model, used on the Watts.happening website. Based on the assumptions set out below, the input provided by the user and the data of the aFRR auction and activation in Belgium from **01/05/2023 to 30/04/2024** (the calculation period), the model calculates the yearly remuneration potential of an asset's participation in the aFRR product. These results are displayed in the "Watts.happening" simulator.

It shall be noted that this is an historical analysis given as an indication. The market context, (connection to EU platforms) has evolved since.

Note that the model is limited to one selected asset and does not consider the interaction with other assets or flexibility products.

2 User input

The user is required to provide information about:

- The maximum power of its asset as well as operating limits, such as the non-flexible part and the running set-point. This information allows the model to define the Upward and Downward Capacity of the asset.
- The Capacity Bidding Price, if any. This represents the minimum price below which the asset will not participate in a capacity auction. It can be a different price for upward and downward flexibility.
- The availability of the asset. This input takes into account the availability constraints, due to the asset's schedule, maintenance or unforeseen events, by means of an Availability factor.
- The Activation Profile the asset follows for the energy activation. The user has the choice between two types of profiles: Balanced and Passive (more information in the section **Error! Reference source not found.**).

3 Data sources

All data used in the model are publicly available on Elia's website or via the Open data platform. To build the model the following data have been used:

- aFRR Capacity Auction results: Capacity - Auction results (elia.be)
    - *Total Awarded Volume aFFR Downward & Upward* (MW)
    - *Average Price aFFR Downward & Upward* (€/MW/h)
    - *Marginal Price aFFR Downward & Upward* (€/MW/h)
- aFRR Available Energy: Data Download Page (elia.be)
    - *Upward Bid Price aFRR* (€/MWh)
    - *Upward Bid Volume aFRR* (MW)
    - *Downward Bid Price aFRR* (€/MWh)
    - *Downward Bid Volume aFRR* (MW)
- aFRR Activated Volume & Price: Energy - Activated volumes and prices 15 min (elia.be)
    - *Upward regulation volume aFRR* (MW)
    - *Downward regulation volume aFRR* (MW)
    - *Incremental Prices aFRR* (€/MWh)

  - *Decremental Prices aFRR* (€/MWh)
- Day-Ahead Price: Day-ahead reference price (elia.be)
  - *Reference Price* (€/MWh)

4 Assumptions

Some assumptions are made in order to keep the model from being too cumbersome while still giving relevant results. The model assumes:

- The model only concerns the Belgian area.
- The model deliberately simplifies the aFRR capacity merit order. To do, the model considers each CCTU separately without taking into account different round of optimization. The Capacity Remuneration is therefore at the level of the CCTU.
- Capacity remuneration is calculated based on the maximum between the 70% of the *Average Price aFFR Downward & Upward* and the Capacity Bidding Price. Internal studies have shown that market participants have difficulties in obtaining more than 70% of the average capacity auction price for aFRR.
- The simulated Capacity bid does not impact the aFRR Capacity Auction results.
- If the Capacity bid is not rewarded and then the Allocated Volume equals 0, we assume that the asset will participate as a free bid in the Activation Merit Order.
- The simulated Capacity Bid does not impact the Activation Merit Order.
- The Capacity Bid is divisible.
- The Activated Energy does not impact the Energy Bidding Price.
- The Energy Bidding Price and the Activated Energy are defined based on the Activation Profile. The model assumes two Activation Profile: Balanced and Passive:
  - For the Passive profile. The asset is considered as the last Energy Bid in the Activation Merit Order. For Upward Flexibility, the price was set at the 99th percentile of the merit order, while for Downward Flexibility it was set at the 1st percentile. These thresholds may be subject to change based on user feedback.
  - The Balanced profile is considered by the model as the 50th percentile Energy Bid of the Activation Merit Order. For Upward and Downward Flexibility, the value has been set to the median price of the Activation Merit Order.
- The Energy Bid is divisible.
- No extra activation cost:
  - No grid cost, tariffs and taxes
  - The renewables (with near zero cost or negative cost due to subsidies) don't have curtail threshold originally. They would produce even at negative net gain.
  - No degradation costs
  - No efficiency loss
- Additional battery assumptions:
  - Since it is not realistic for a battery to reserve all its charge capacity in the aFrr market, there is additional restrictions based on battery depth (the ratio of the charge capacity and max power)
    - Battery depth ≤ 1h: Not suitable for aFrr market
    - 1h < Battery depth ≤ 2h: 25% of power capacity to participate
    - 2h < Battery depth ≤ 3h: 50% of power capacity to participate
    - 3h < Battery depth ≤ 4h: 60% of power capacity to participate
    - Battery depth > 4h: 70% of power capacity to participate

- Additional renewable assets assumptions:
  Renewable assets (solar and wind) are simulated based on its full installed capacity. Due to the intermittency of renewables, additional assumptions are made to compensate the load factor of the assets.
  - Solar:
    - Only hours 8 to 16 during the day are simulated.
    - An average capacity factor of 27% was observed during the simulation period, at hours 8 – 16. A 27% correction factor is applied to the end results.
  - Wind:
    - An average capacity factor of 23% was observed during the simulation period. A 23% correction factor is applied to the end results.

Some of these assumptions will change as the model evolves.

5 Model

The model works in two stages. Firstly, it calculates the Capacity Remuneration and secondly the Energy Remuneration.

5.1 Capacity Remuneration

The calculation of the Capacity Remuneration consists in three steps:

- The **first step** is to simulate a Capacity Bid for all auctions of the calculation period in which the asset can participate based on its availability.
  - For upward flexibility, the model takes the Upward Capacity of the asset.
  - For downward flexibility, the model takes the Downward Capacity of the asset.
  - The model simulates Capacity Bid either for the CCTU 00-24 or for one or more 4 hours CCTU. The asset cannot participate in both.
  - No Capacity bid will be created for auctions that are part of the unavailability periods mentioned by the user.
- The **second step** is to take account of the asset's activation constraints. There are two of these, Activation Frequency and Activation Time. The constraint on Activation Frequency aims to apply a filter on the day on which the asset will participate in flexibility, while the constraint on Activation Time consists of applying a second filter on the hours of participation of the days selected in the previous filter.
  - For the Activation Frequency, there are 4 possibilities:
    - Every day: in which case no additional constraints are applied. All the days will be taken into account by the model for the next step, except for unavailability periods mentioned by the users in the previous step.
    - Max once a week: for this, the model will select only one day per week and the remuneration will be calculated solely on that day. If the Upward Capacity is greater than or equals to the Downward Capacity:
      - Then it selects the day with the highest average *Marginal Price aFFR Upward (€/MW/h)* of the week.
      - Else, it selects the day with the highest average *Marginal Price aFFR Downward (€/MW/h).*
    - Max once a month: In this case, the model applies the same logic as for max once a week, but this time takes just one day per month.
    - Max once a year: In this case, the model applies the same logic as for the maximum once a week, but this time it is a single day over the whole year.

  - For the Activation Time, the model considers 3 possible cases.
    - 15min; 1 hour; 2 hours: In the case of the aFRR product, the minimum Activation Time to participate in the flexibility product is 4 hours. For an Activation Time under 4 hours, the model considers that the asset does not meet the product's prerequisites and therefore cannot receive any remuneration.
    - 4 hours; 8 hours; 12 hours: if the Upward Capacity is greater than or equals to the Downward Capacity:
      - Then, the model takes into account respectively one, two or three periods with the highest *Marginal Price aFRR Upward (€/MW/h)* of the day. The other periods will not be considered when calculating the remuneration.
      - Else, the model takes into account respectively one, two or three periods with the highest *Marginal Price aFRR Downward (€/MW/h)* of the day. The other periods will not be considered when calculating the remuneration.
    - No limitation: the model does not apply a filter to the days. All periods are taken into account.
- The **third step** is to define for each auction period whether the Capacity Bid is rewarded or not based on the Capacity Bidding Price.
  - First the model defines the Capacity Bidding Price. This price is set by default according to the type of asset selected. However, the user has the possibility to enter a price constraint as explained above. If this is the case, the model considers the Capacity Bidding Price as this price constraint.
  - Then, for each CCTU, the model checks whether the Capacity Bidding Price is bigger than the *Marginal Price* of aFRR Upward and Downward:
    - If so, the model considers the Capacity Bid as rewarded. It means the Allocated Capacity is equals to the Capacity Bid. However, Allocated Capacity cannot be greater than *Total Awarded Volume* of the CCTU.
    - If not, the model considers the Capacity Bid as not rewarded. So, the Allocated Capacity equals 0 MW.
- The **fourth step** consists in calculating the Capacity Remuneration of the asset for the calculation period.
  - For aFRR, as it is pay-as-bid remuneration, the model must define the price of the bid. For each CCTU of the calculation period, the model takes the maximum between 70% of the *Average Price* and the Capacity Bidding Price and multiplies it by the Allocated Capacity to get Capacity Remuneration of the asset for Upward Capacity and Downward Capacity (more information in the section **Error! Reference source not found.**).
  - In addition, the model also applies an Availability factor to the Capacity Remuneration in order to take into account possible unavailability of the asset due to maintenance or unforeseen events. This Availability factor is set at 100% by default but can be modified by the user.

5.2 Energy remuneration

The calculation of the Energy Remuneration is done in five steps:

- The **first step** is to apply two filters.

- The first filter consists of removing periods that are part of asset unavailability periods explicitly mentioned by the user.
- The second filter consists of applying the same filtering rules as for Capacity Remuneration as a function of Activation Frequency and Activation Time. In other words, the model calculates the Energy Remuneration only for the periods selected following this filtering. There is an exception if the Activation Time is less than 4 hours. In this case, the filtering rules are as follows:
  - 15 min: no Energy Remuneration is considered for this short Activation Time.
  - 1 hour & 2 hours: on the selected days, for the upward flexibility, the model takes respectively the hour or the two hours for which the *Upward regulation volume aFRR* (MW) is the highest. For downward flexibility, the model takes respectively the hour or the two hours for which the *Downward regulation volume aFRR (MW)* is the highest.

- The **second step** is to define the Energy Bidding Price of the asset for each quarter hour of the selected period at the previous step. This price is defined according to the Activation Profile chosen by the user.
  - For Upward Flexibility:
    - If it is the balanced profile, the Energy Bidding Price will be equal to the median price of all the *Upward Bid Price* available for the quarter hour in question (see assumption).
    - If it is the passive profile, the Energy Bidding Price will be equal to the 99th percentile of all the *Upward Bid Price* available for the quarter hour in question (see assumption).

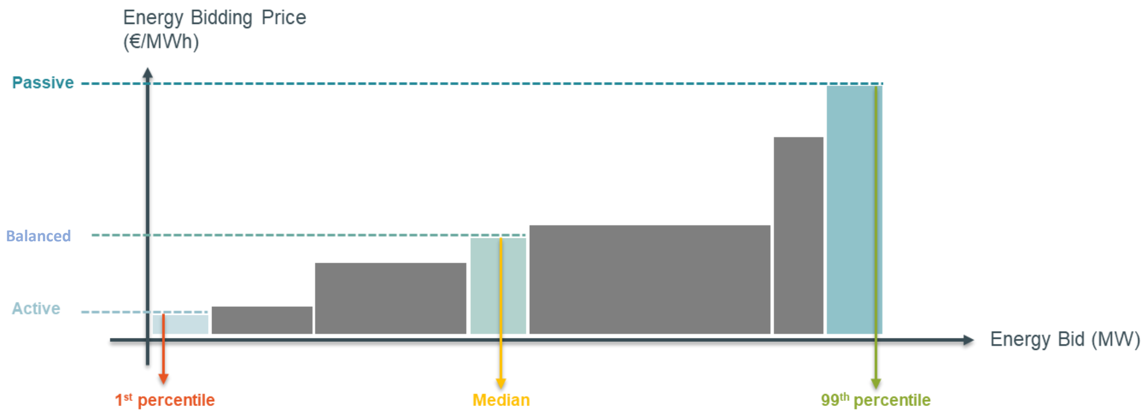


Figure 1. Energy bidding price definition for Upward energy activation (The active profile is a legacy profile, and is currently not implemented)

  - For Downward Flexibility:
    - If it is the balanced profile, the Energy Bidding Price will be equal to the median price of all the *Downward Bid Price* available for the quarter hour in question.
    - If it is the passive profile, the Energy Bidding price will be equal to the 1st percentile of all the *Downward Bid Price* available for the quarter hour in question.

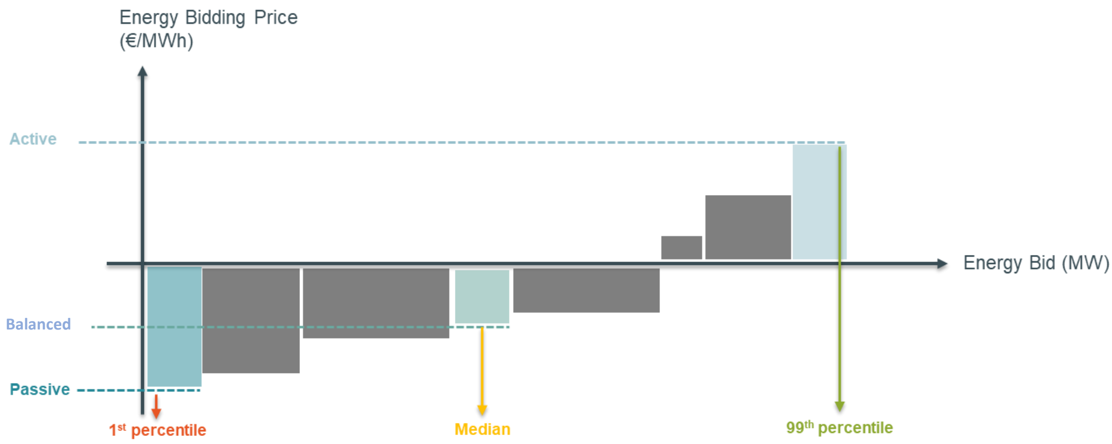


Figure 2. Energy bidding price definition for Downward energy activation (The active profile is a legacy profile, and is currently not implemented)

- The **third step** is to determine the Activated Energy.
  - First, the model defines the Activated Capacity for Upward and Downward flexibility minute by minute. For each minute:
    - The model determines if the Upward or Downward Capacity is considered as Activated Capacity depending on the value of *aFRR Control Target Value (proxied by the net of the positive and negative aFRR capacity requested in each minute observation)* and the Activation Profile and calculated the volume of it:

For the Balanced Profile:

- if *aFRR Control Target Value* is positive and bigger than Mid Bid Value Up, then Activated Capacity equals the minimum between *aFRR Control Target Value* minus Mid Bid Value Up and Upward Capacity. Where the Mid Bid Value Up equals the 50th percentile of the size of the Activation Merit Order of *Upward Bid Volume aFRR* for each quarter hour of the calculation period.
- if *aFRR Control Target Value* is negative and lower than Mid Bid Value Down, then Activated Capacity equals the minimum between *aFRR Control Target Value* minus Mid Bid Value Down and Downward Capacity. Where the Mid Bid Value Down equals the 95th percentile of the size of the Activation Merit Order of *Upward Bid Volume aFRR* for each quarter hour of the calculation period.

For the Passive Profile:

- if *aFRR Control Target Value* is positive and bigger than Last Bid Value Up minus the Upward Capacity, then Activated Capacity equals the minimum between Upward Capacity and *aFRR Control Target Value* plus Upward Capacity minus Last Bid Value Up. Where the Last Bid Value Up equals the 95th percentile of the size of the Activation Merit Order of *Upward Bid Volume aFRR* for each quarter hour of the calculation period.
- if *aFRR Control Target Value* is negative and lower than Last Bid Value Down plus Downward Capacity, then Activated Capacity equals the minimum between the Downward Capacity and Last Bid Value Down plus Downward Capacity minus *aFRR Control Target Value*. Where the Last Bid Value Down equals the 95th percentile of the size of the Activation Merit Order of *Downward Bid Volume aFRR* for each quarter hour of the calculation period.

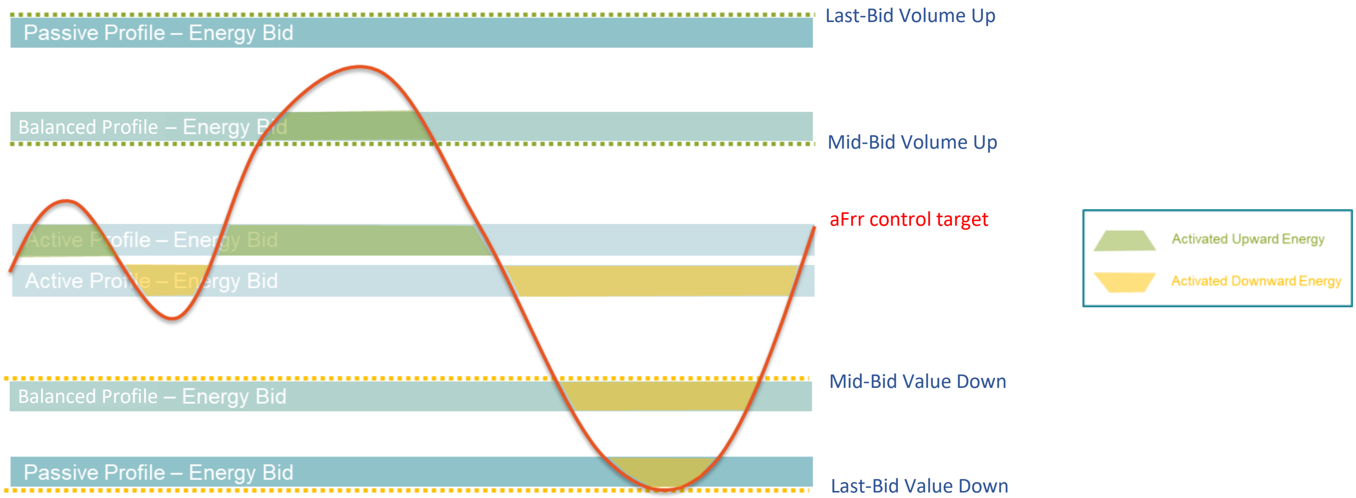


Figure 3. Activated energy calculation based on aFRR Control Target (The active profile is a legacy profile, and is currently not implemented)

- Depending on the Activation Profile, the model aggregates the one-minute value of Activated Capacity for each quarter hour of the calculation period and transforms it into Activated Energy. The model also excludes all quarter hours that are part of the unavailability constraints mentioned by the user.

- The **fourth step** consists in calculating the Energy Remuneration.
  - For Upward Flexibility:
    - As it is pay-as-bid market for energy, the model multiplies the Activated Energy by the Energy Bidding price defined as the first step.
  - For Downward Flexibility:
    - As it is pay-as-bid market for energy, the model multiplies the Activated Energy by the Energy Bidding price defined as the first step.
  - **(aFrr energy acution becomes pay-as-cleared from November 2024. The simulation will update accordingly when the calculation period is updated)**
  - In addition, the model also applies an Availability factor to the Energy Remuneration in order to take into account possible unavailability of the asset due to maintenance or unforeseen events. This Availability factor is set at 100% by default but can be modified by the user.
  - For information, the following convention is applied to the payment for balancing energy:

	Balancing energy price positive	Balancing energy price negative
Upward flexibility energy	Payment from Elia to Asset	Payment from Asset to Elia
Downward flexibility energy	Payment from Asset to Elia	Payment from Elia to Asset

- The **last step** is the calculation of Energy Difference Cost:
  - This step is to compensate the difference between upward and downward activation energy. The cost of the energy difference is determined based on the net position over the year, and which type the asset is.
  - Storage and Load asset: These two types of assets try to maintain net 0 in activation. They will compensate the energy difference in the day-ahead market.

        - Net upward activation: the asset buys the insufficient energy at the 20th percentile price of the day-ahead market
        - Net downward activation: the asset sells the excess energy at the 80th percentile price of the day-ahead market
    - Producer asset: the cost of producing is the LCOE and is provided as a user input.
    - Renewables: Only downward activation and there is no cost for activation (curtailing)

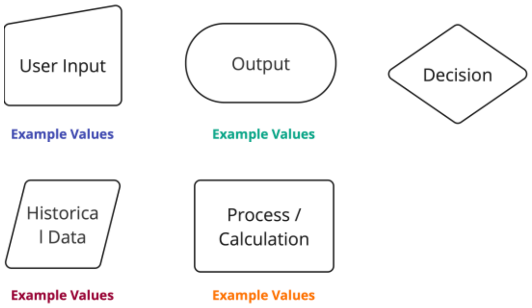
6 Output

The model generates the following outputs:

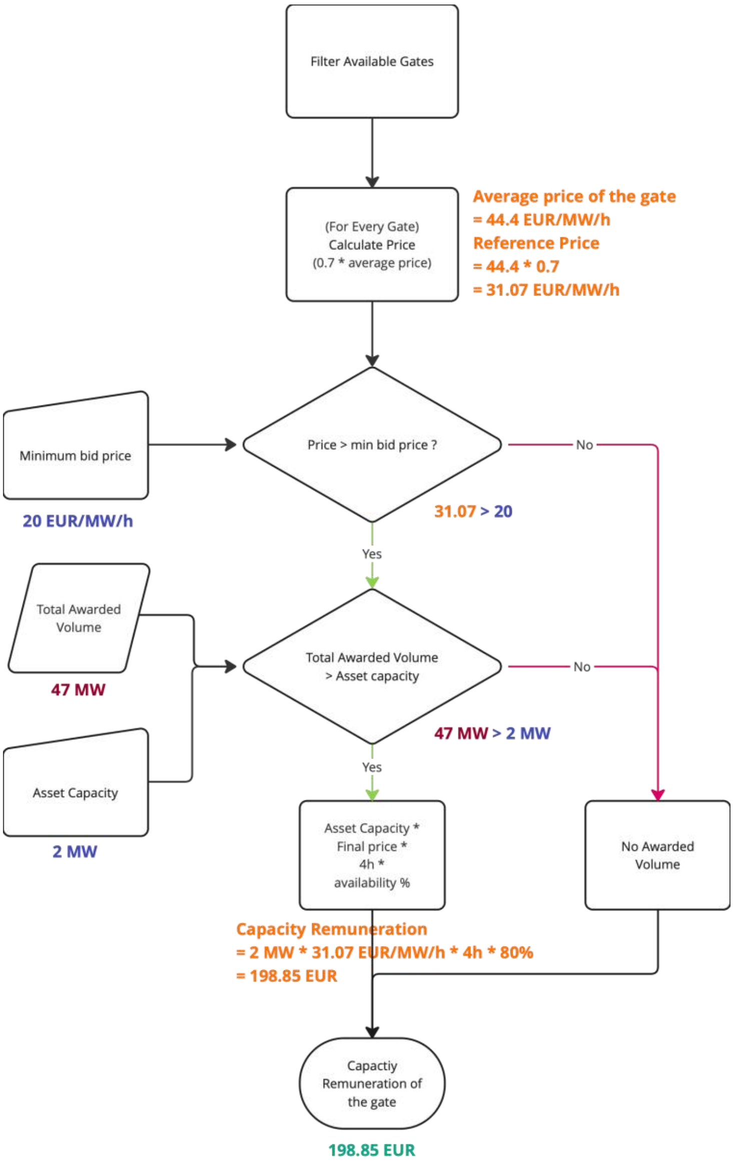
- For the capacity:
    - The Capacity Remuneration for Upward Capacity and Downward Capacity as described hereabove. It is expressed in € per year.
    - The Bid Allocation Percentage indicates to which extent the Capacity bid is considered as Allocated Volume by the model. If it equals 100%, it means that the asset capacity is rewarded for every auction in which it participates.
- For the energy:
    - The Energy Remuneration for Upward Energy Activation and Downward Energy Activation as described hereabove. It is expressed in € per year.
    - The Energy Activation Percentage indicates the proportion of energy the asset is activated to provide flexibility with respect to the maximum available flexible energy. 100% means that the asset is offering flexibility at **full power** all the time, while 0% means that it has never been activated.
- The Gross Margin is the total potential benefit of participating in the market. It is the addition of the Total Capacity Remuneration and Total Energy Remuneration subtracting the Energy Difference Cost.
- If the asset is a storage asset, an Average Daily Cycle is also calculated. The value is calculated as the average daily discharged divided by the available charge capacity. Note the denominator is the available part instead of the actual maximum charge capacity.

7 Example Calculations

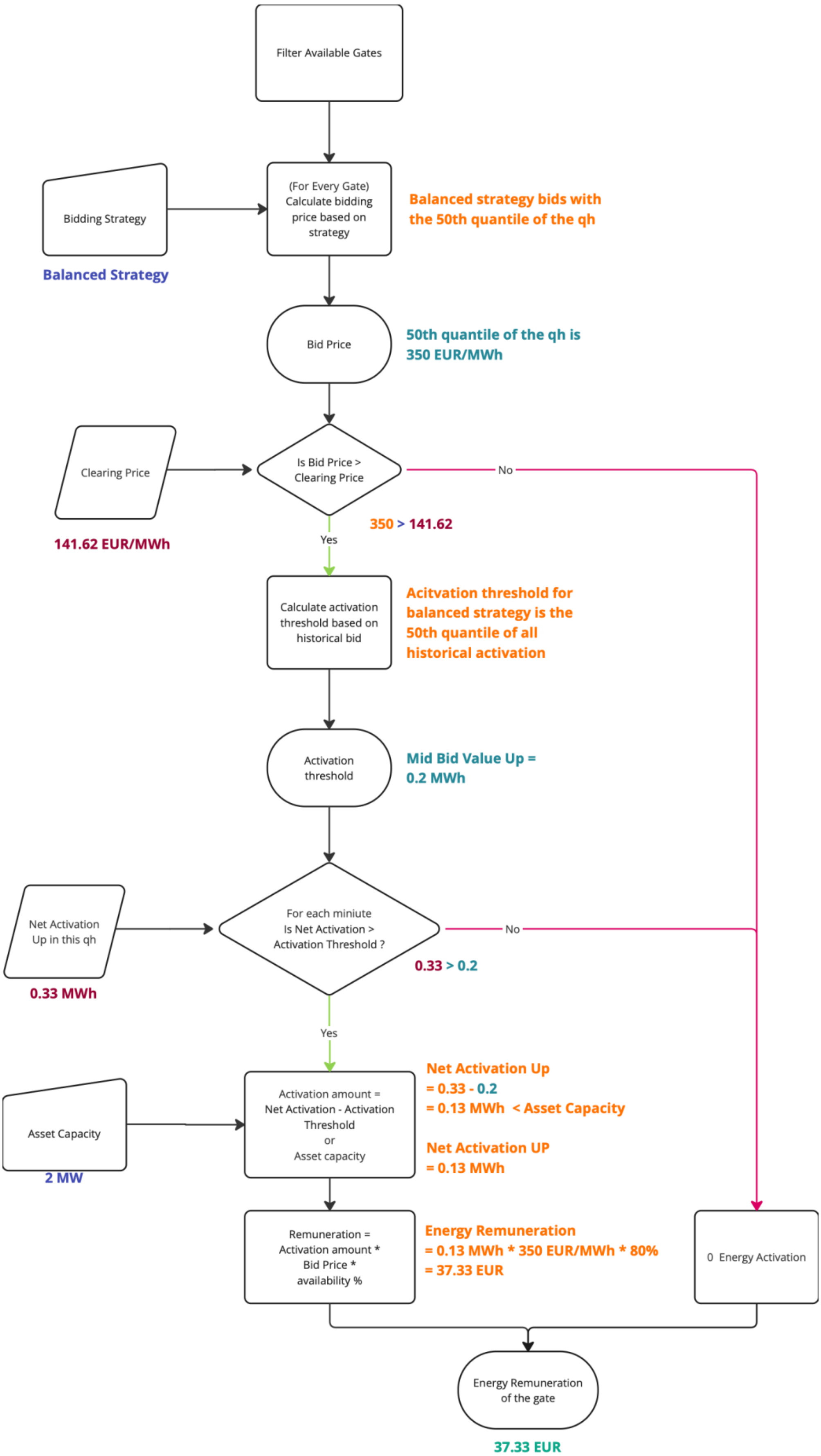
The following shows an example of a battery asset at 2023/05/01
Upward and Downard capacity = 4 MW
Charge capacity = 12 MWh
Due to battery power reserve assumptions, a 3-hour battery would only have 50% of the max power capacity participate in aFrr. Therefore, the power capacity used in the calculation is 2MW.



Upward Capacity Remuneration Example 2023/05/01 00h-40h



Upward Energy Remuneration Example 2023/05/01 00:00-00:15



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