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ICEBERG Interim Workshop

Interactions Between Imbalance Settlement and Cross-Border Balancing

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Introduction
Regulatory Context

- **Imbalance Settlement** constitutes a core element of the balancing market clearing procedure
  - Charges or remunerates Balancing Responsible Parties for their imbalances
  - European directives aim at the harmonization of the imbalance settlement procedures in all regions
- Imbalance settlement price is an important element since it provides adequate economic signals to BRPs to either balance their position or help the system to return to balanced conditions
  - May follow the single or dual pricing methodology
  - Applied over the duration of an imbalance settlement period, i.e. 15 minutes
- In Belgium there are currently two major approaches:
  - The regulator CREG aims to enhance the **efficient operation** of the pan-European system
  - The transmission system operator ELIA is concerned about the **system security**

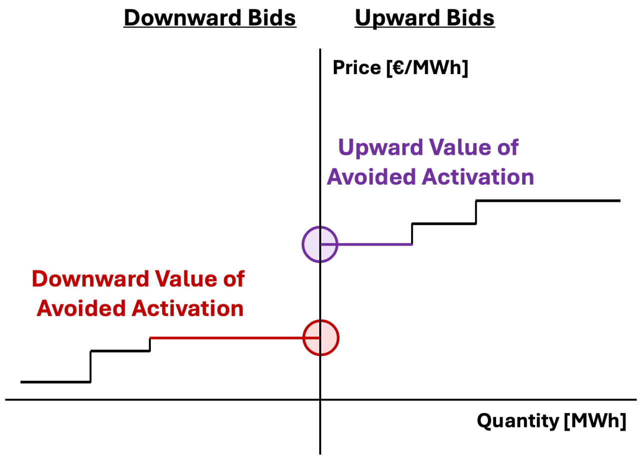
Introduction

Imbalance Settlement Price – Price Components

- **Weighted Average Price (WAVG):** Weighted average, with regard to absolute system imbalance, Cross Border Marginal Price
  - IMB: System Imbalance
  - CBMP: aFRR Cross Border Marginal Price

$$\mathbf{WAVG} = \frac{\sum_t(\mathrm{abs}(\mathrm{IMB}_t) * \mathrm{CBMP}_t)}{\sum_t(\mathrm{abs}(\mathrm{IMB}_t))}$$

- **Value of Avoided Activation in Upward/Downward direction (VoAAup and VoAAdn):** Value of the first bid for providing Upward and Downward balancing energy



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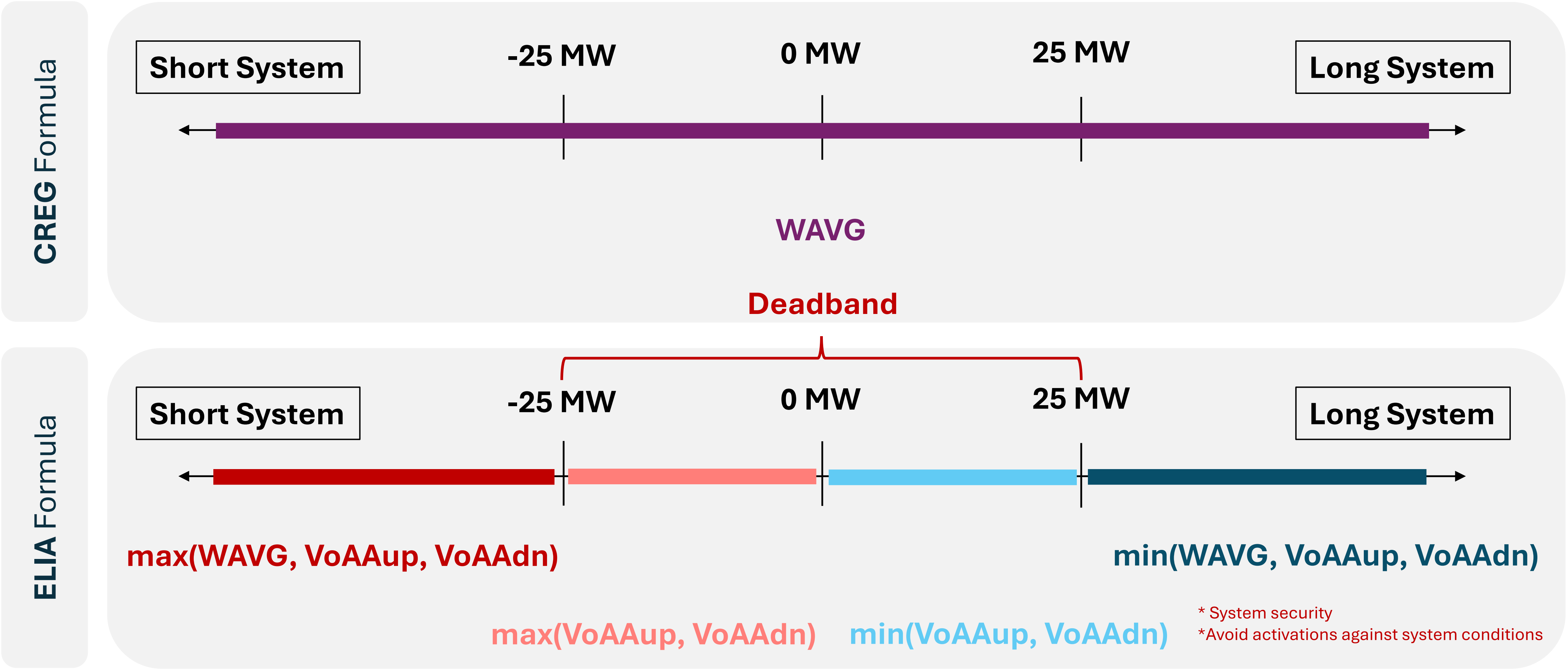
Introduction

Imbalance Settlement Price – Existing Formulas



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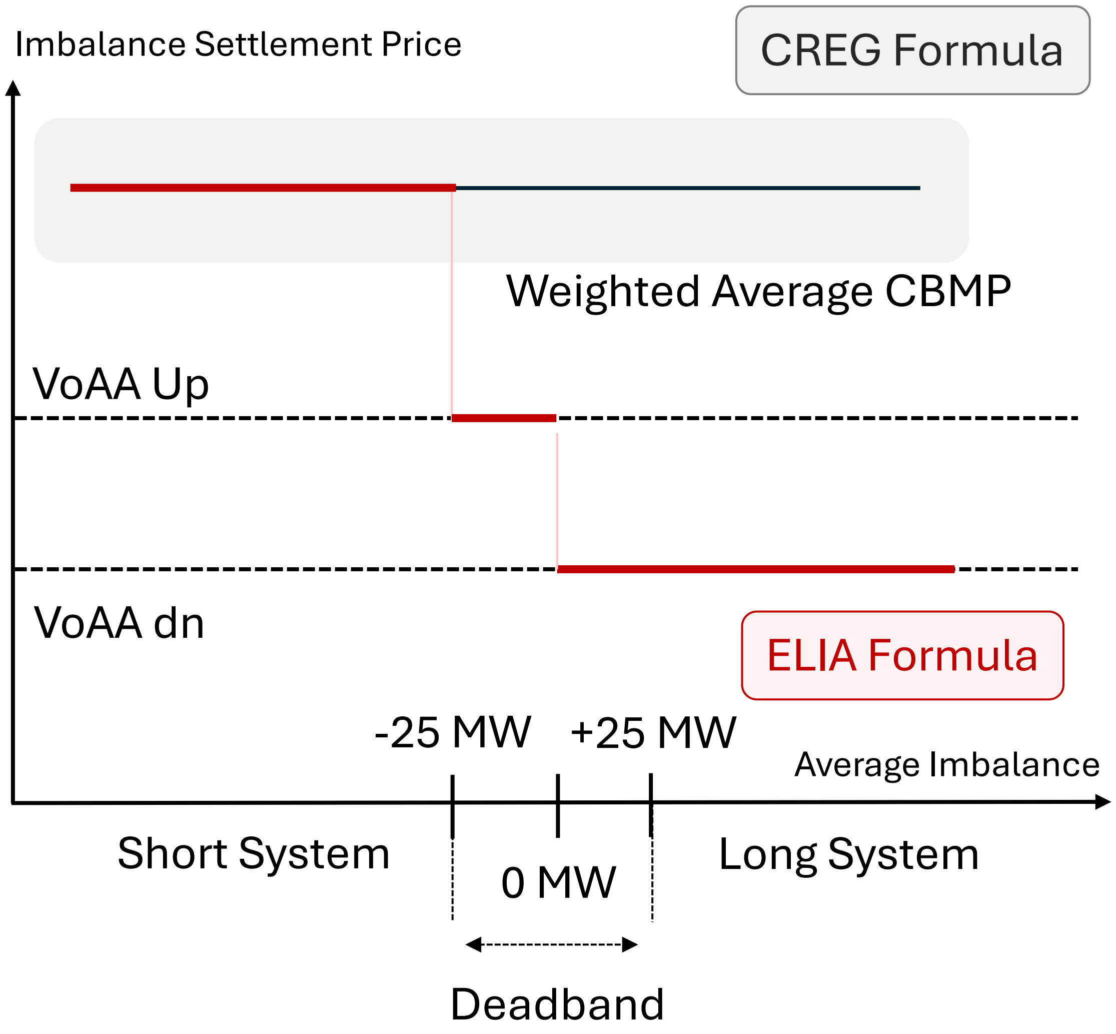
Introduction

Imbalance Settlement Price – Graphical Representation



Introduction

Project Scope

Participant bahavior against the various imbalance price settlement schemes

Model

Quantify

Efficient pan-European system operation and system security

Identify

Different granularity between the imbalance settlement period and the underlying price components

Model Description

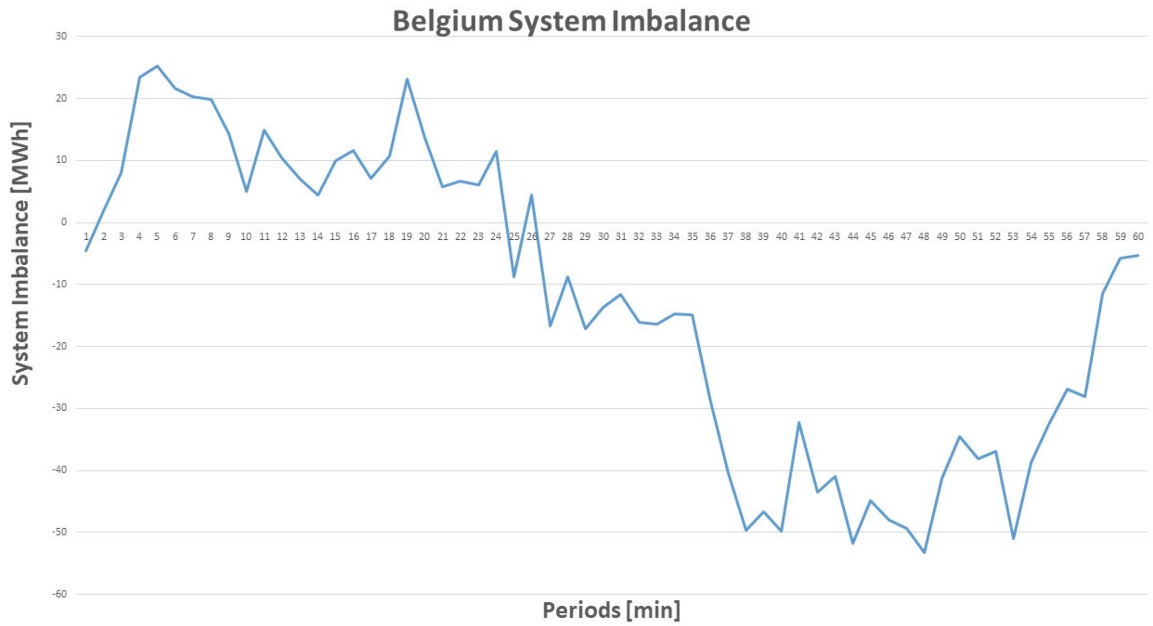
Imbalance Time-Series Generation Model

- ❑ In the analysis, **a first-order stationary autoregressive model (AR1)** was used, for creating each bidding area imbalance

$$Imb_t = \varphi \cdot Imb_{t-1} + \varepsilon_t$$

- ❑ ε_t is the white noise → sampled from a normal distribution

- ❑ A continuous imbalance is created, for **X** minutes → separated in **X/15** scenarios → training/testing of the reinforcement learning model



AR1 model with **mean value** equal to **0**

Model Description
Balancing Platform

min {**Balancing Energy Procurement** (Beup,BEdn)}

s.t.

Balancing Energy Activation Limits (Beup, BEdn)

Zonal Power Balance Constraint (Eaa', Beup, BEdn) : (**λ**)

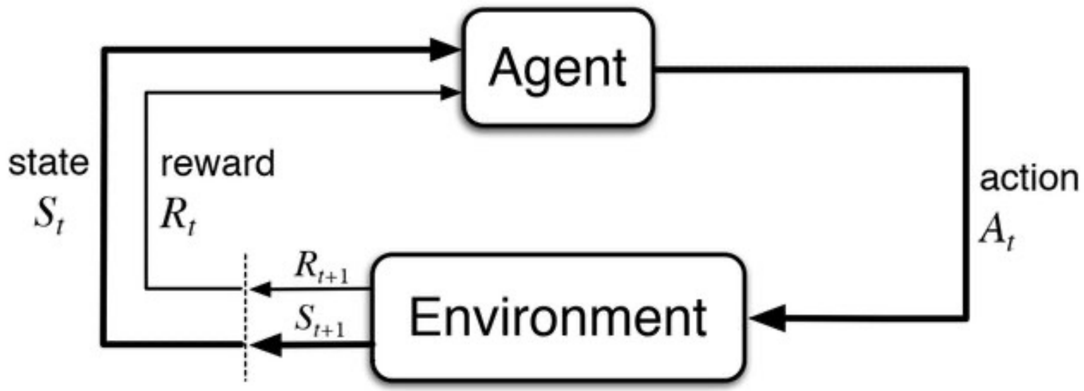
Available Transfer Capacity (ATC) Limits (Eaa')

Simplified version of the PICASSO algorithm
Linear Programming Model

- Balancing energy procurement (=)
  - cost of upward balancing energy (**BEup**) activation
    (-)
  - utility of balancing energy down (**BEdn**) activation
- Negative/Positive imbalance translates to short/long system conditions
- Additional slack variables have been incorporated to ensure problem feasibility
- Cross Border Market Price: dual multiplier **λ** of the power balance constraint for each 1-minute

Model Description

Reinforcement Learning Model (1/5) – Basic Concepts



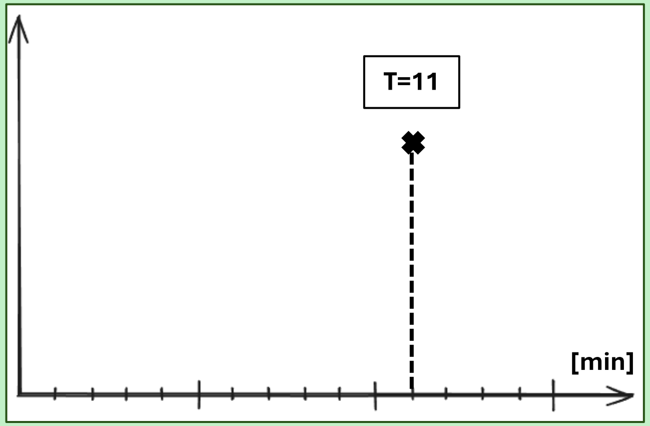
** Source: Richard S Sutton and Andrew G Barto. Reinforcement learning: An introduction. MIT press, 2018*

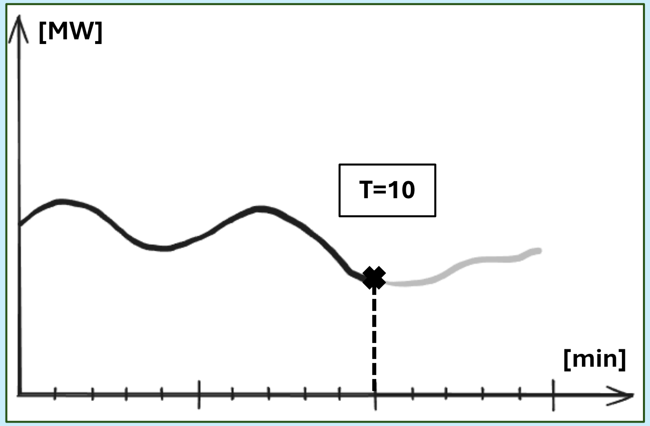
- The agent operates in a predefined environment that is described by the **state variables**
  - In this study: the course of the 15-minute imbalance settlement period
- **Actions** constitute the decision of the agent
- The result of this action is quantified through a **reward** → performance of the agent to its overall goal
- Agent is trained against a sufficient large number of 15-minute imbalance and price scenarios → **episodes**

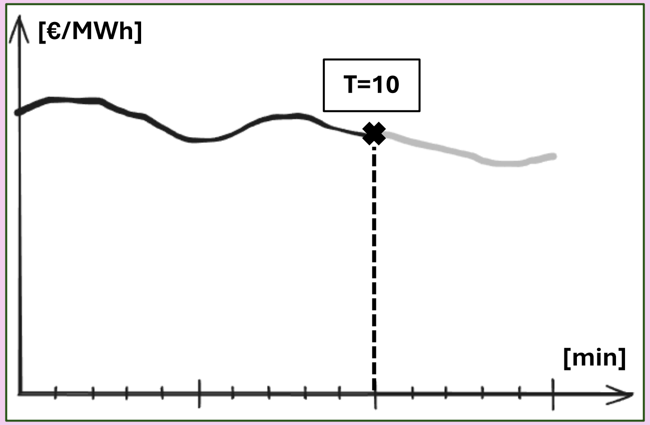
Model Description

Reinforcement Learning Model (2/5) – Examined States

Trading Period	Average Imbalance	Weighted Average Price
Current Period	Up to the **Previous** Period	Up to the **Previous** Period



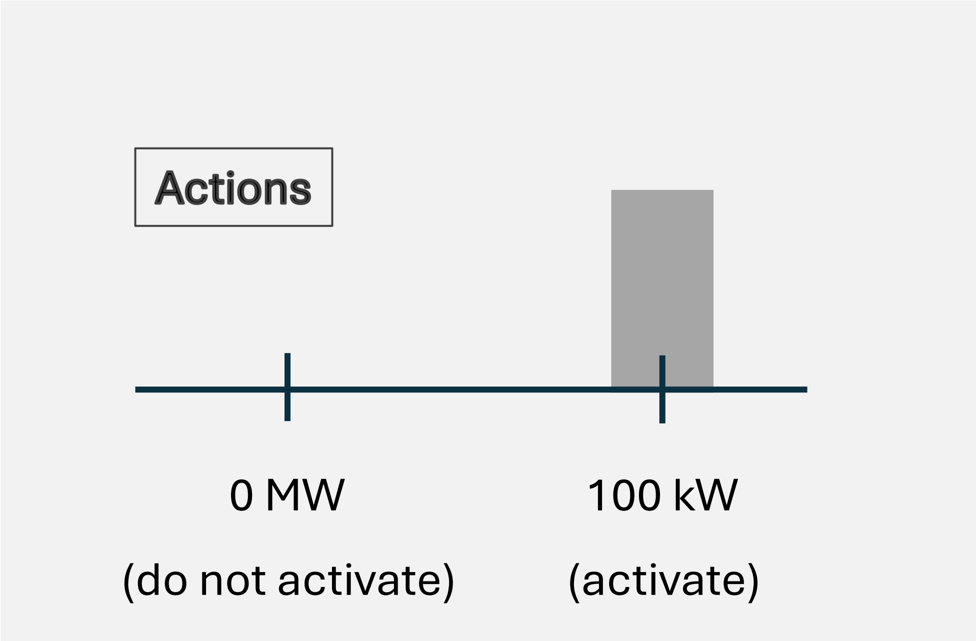




- ❑ Other states may also be taken into consideration, i.e.
  - ➢ Available capacity of the interconnecting line
  - ➢ Available agent capacity
  - ➢ Other
- ❑ Trade-off between agent behavior modelling and computational tractability

Model Description

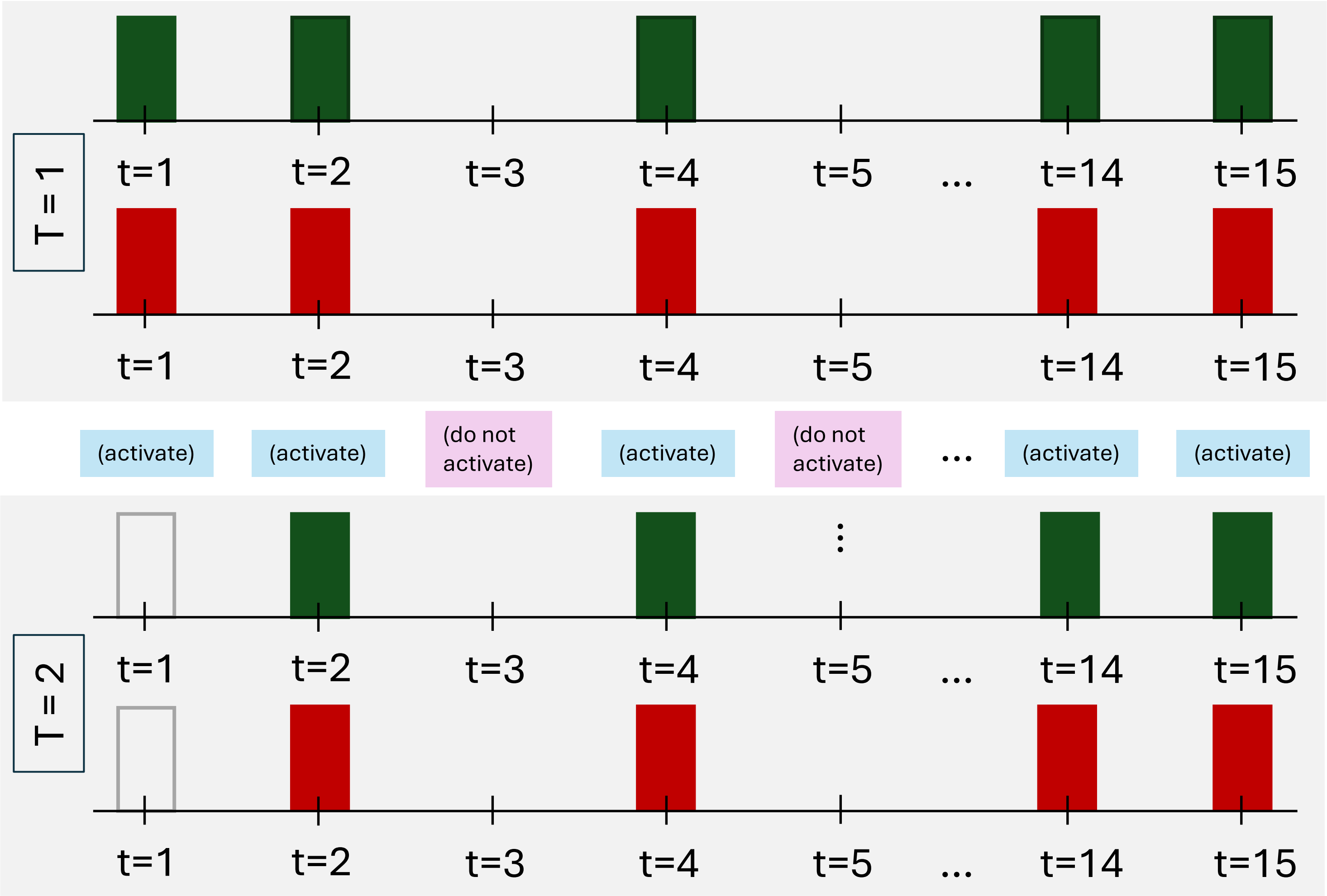
Reinforcement Learning Model (3/5) – Examined Actions



- ❑ Only two actions were examined to ensure computational tractability
- ❑ In each episode (scenario):
  - ➢ Optimal actions for each state vector are selected → **maximum Return**
  - ➢ Actions are updated based on the **ε-greedy algorithm** → There is a possibility that another action will be selected with probability **ε/(No of Actions)**

Model Description

Reinforcement Learning Model (4/5) – Calculation of Rewards



- Agent maximizes the expectation of **return** G_t over all following **rewards** $R_t \dots R_T$

$$\boldsymbol{G_t = R_t + R_{t+1} + \dots + R_T}$$

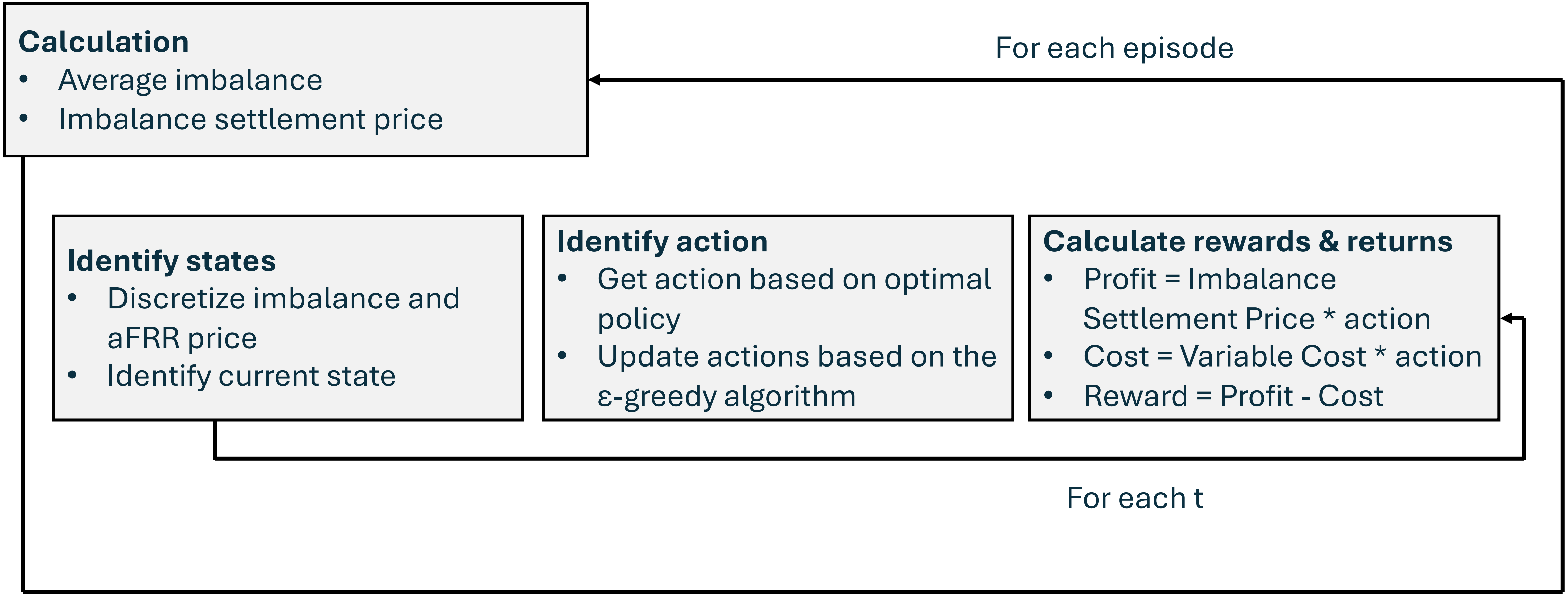
Where:

$$\boldsymbol{G_t = \sum_{\tau=t}^{\tau=T} P^{imb} \cdot a_\tau - \sum_{\tau=t}^{\tau=T} VC \cdot a_\tau}$$

- The return G_t is used to update the overall return vector for the examined state and action
- Optimal action α_t for an examined state is selected based on a policy → maximum return

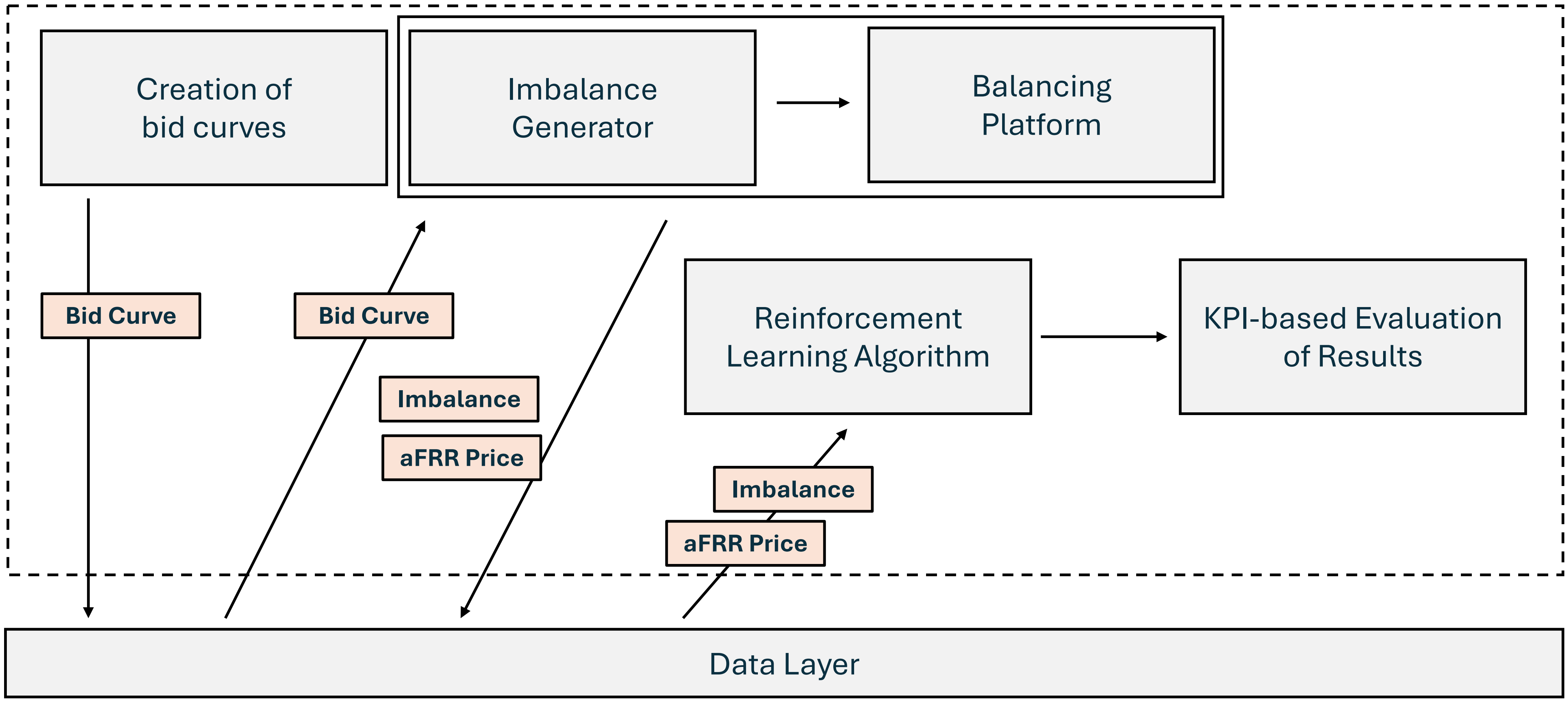
Model Description

Reinforcement Learning Model (5/5) – Overall Algorithm



Model Description

Developed Platform



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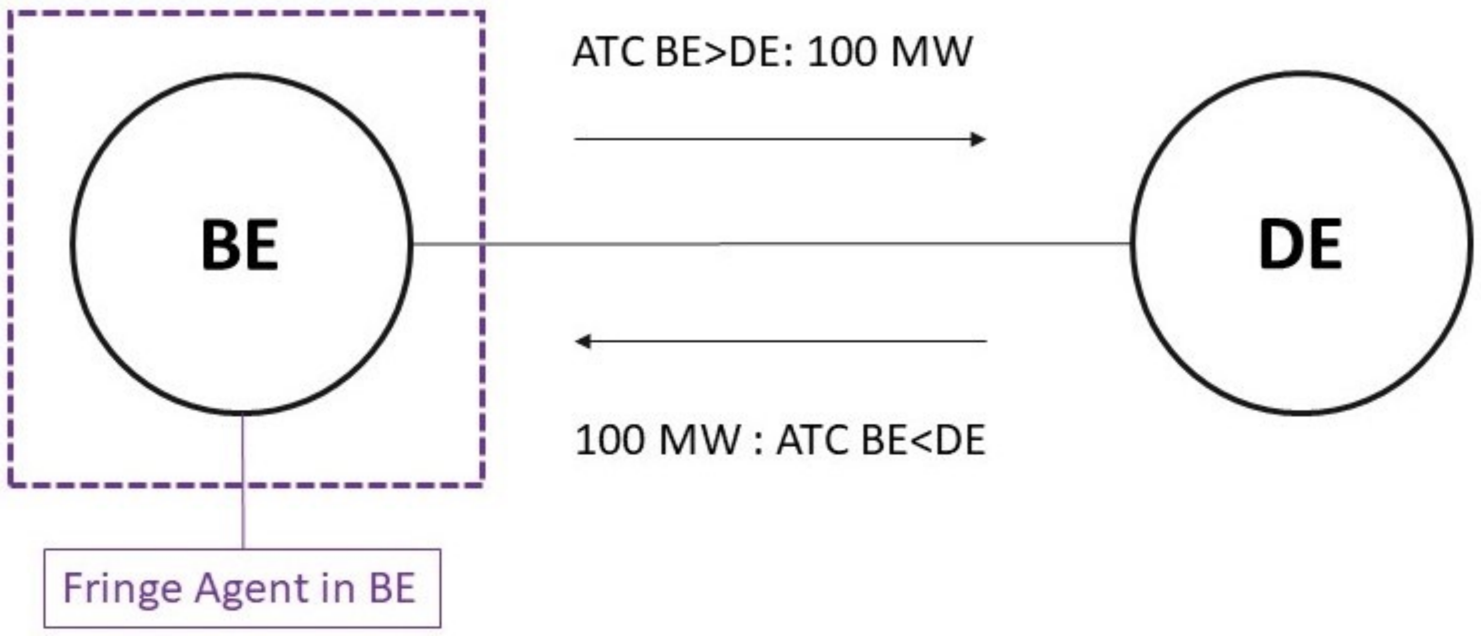
Analysis Settings

Settings in Two-Zone System (1/2) – General Options



- Base case ATC between the two areas → 100 MW on both directions
- Basic parameters for our models
- Algorithm trained against a set of 1,000,000 scenarios and tested against additional 1,000,000 scenarios

Analysis Settings

Settings in Two-Zone System (2/2) – Step Discretization

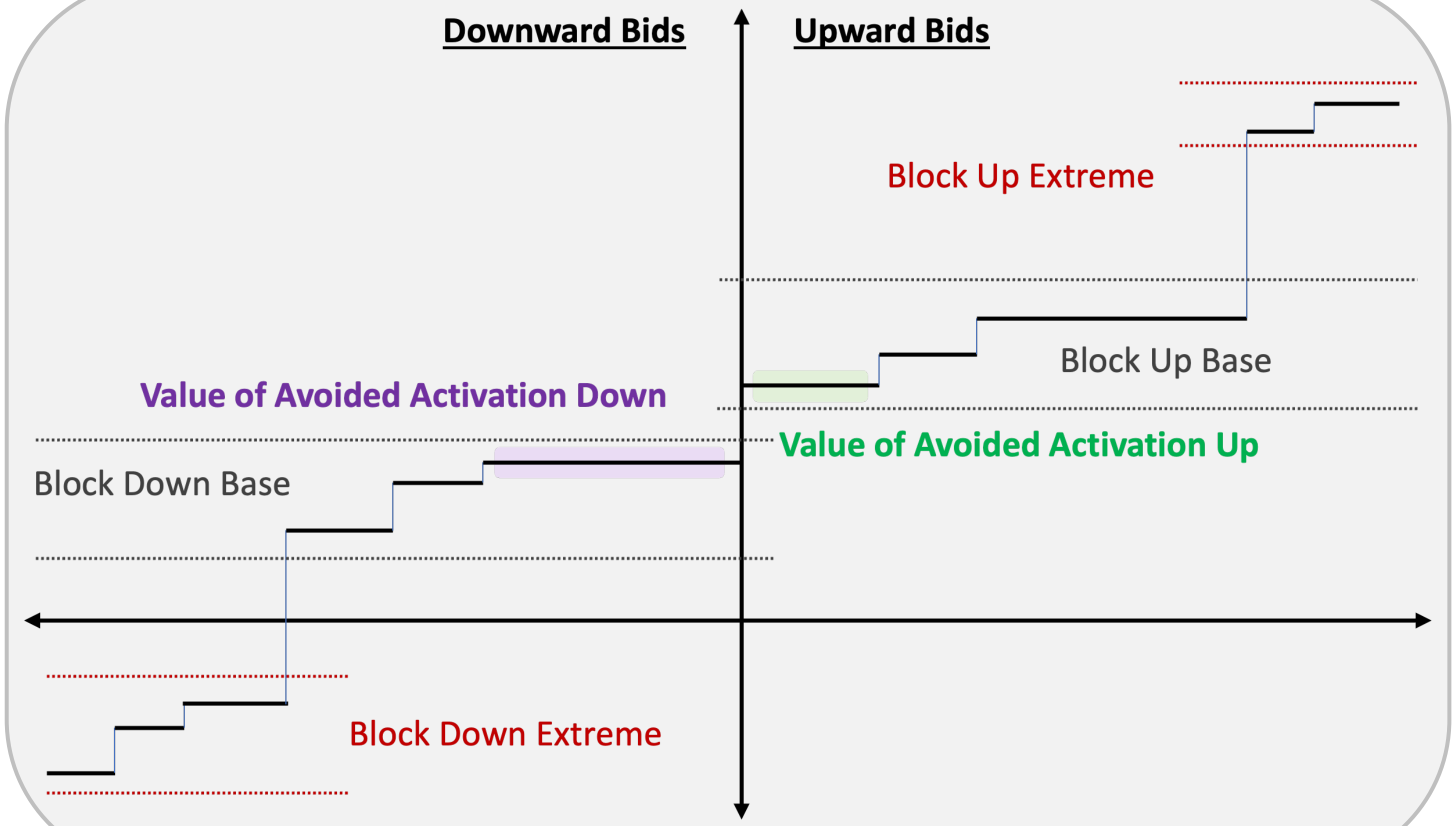
Imbalance Discretization [MW]		
From	To	Step
-10,000	-200	10,000
-200	200	5
200	10,000	10,000

Price Discretization [€/MWh]		
From	To	Step
-10,000	-500	1,000
-500	100	50
100	600	5
600	1,000	50
1,000	10,000	1,000

- Step discretization to ensure computational tractability
- Smaller steps in the imbalance and price areas with more expected instances

Analysis Settings

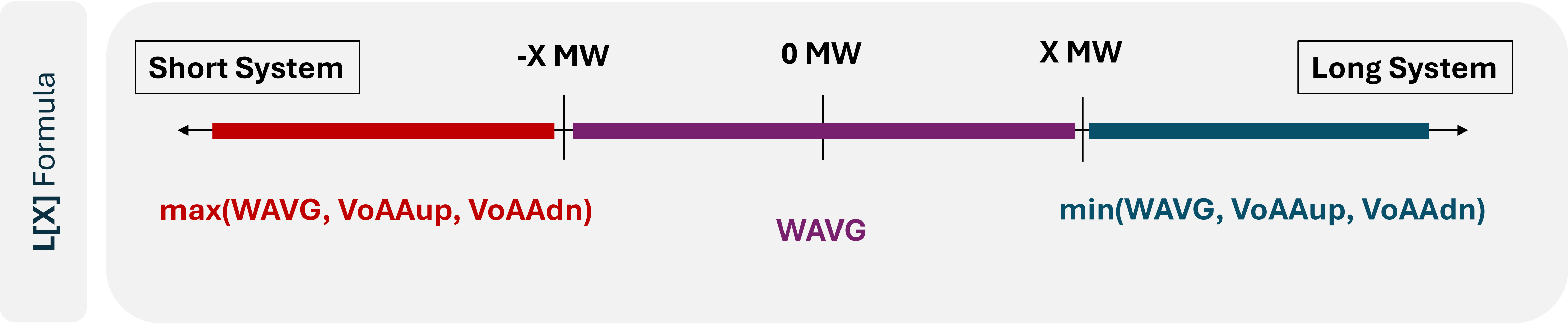
Bid Generation Procedure - Methodology



- Bid generation procedure that creates aFRR random bids for both Belgium and Germany
- Bids are separated in blocks based on the **direction** (upward/downward) and their **price** (base/extreme)
- Basic bid curve parameters:
  - Total offered quantity
  - Minimum offered price
  - Maximum offered price
  - Total number of available bids

Analysis Settings

Imbalance Settlement Price Formulas – Alternative Pricing Scheme



- **Alternative Pricing Formula**: Up until a predefined level L (i.e. 10MW) the imbalance settlement price is calculated based on the CREG formula (only the Weighted Average Price) and above this threshold it is based on the ELIA one (max/min of the three price components)
- Attempting to find a compromise between the European regulations and the TSO's objective to safeguard the system security

Analysis Settings

Definition of Key Performance Indicators

Efficient System Operation

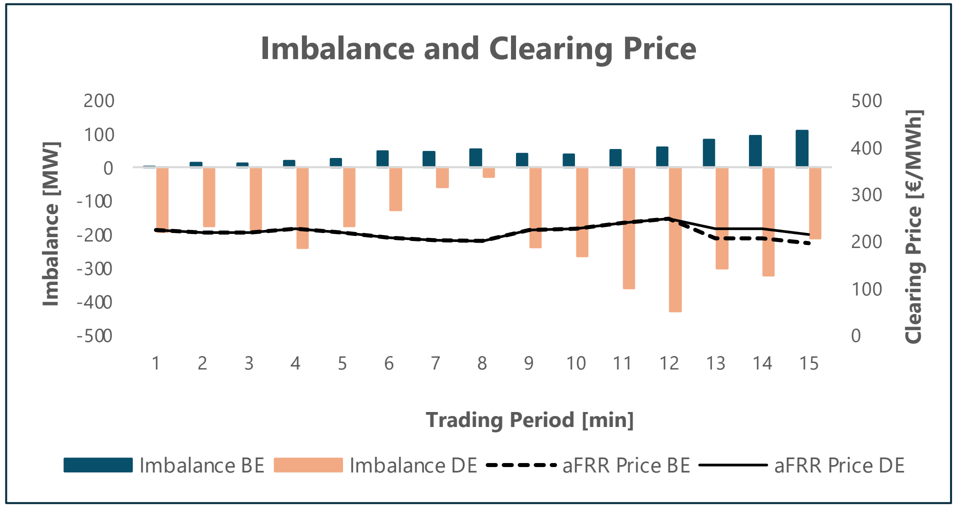
- ❑ **KPI-1**: Percentage of time that the interconnecting line is congested in the BE-DE direction
- ❑ **KPI-2**: Percentage of time that the interconnecting line is congested in the DE-BE direction
- ❑ **KPI-3:** Conditional percentage of time when the interconnecting line is congested in the BE-DE direction and the examined fringe agent opts to increase its production
- ❑ **KPI-4:** Percentage of time that the agent is helping the short pan-European system

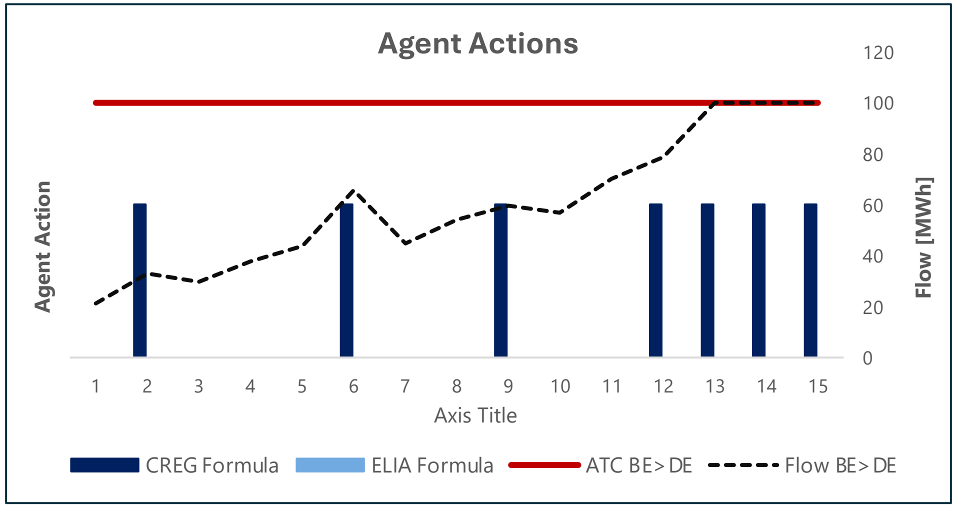
System **Security**

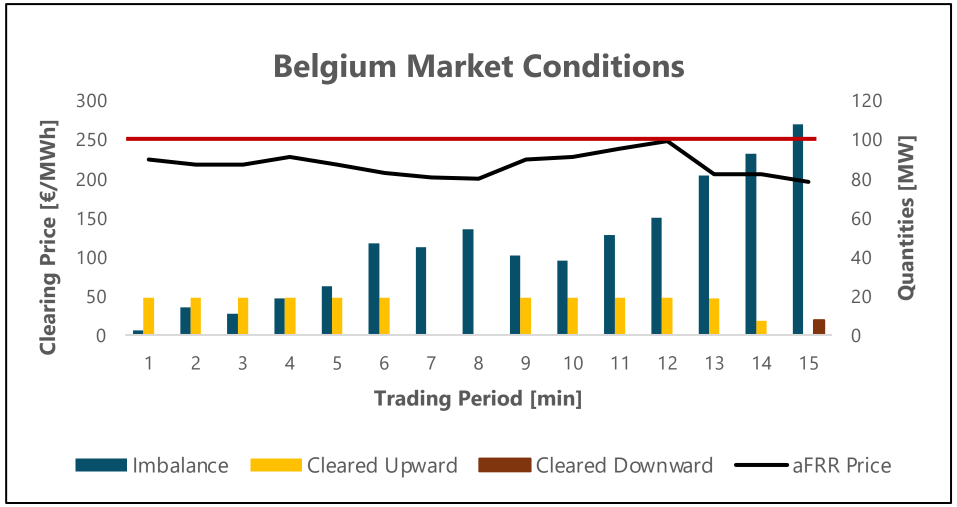
- ❑ **KPI-5**: Percentage of time that the interconnected line is congested in the BE-DE direction, the fringe agent is activated, and the downward bid curve in Belgium is depleted
- ❑ **KPI-6:** Percentage of time that the upward Belgium bid curve is depleted
- ❑ **KPI-7:** Percentage of time that the downward Belgium bid curve is depleted
- ❑ **KPI-8:** Percentage of time that the agent is activated when the downward cleared quantity is more than X% of the downward bid curve

Simulation Results

Two-Zone System Analysis



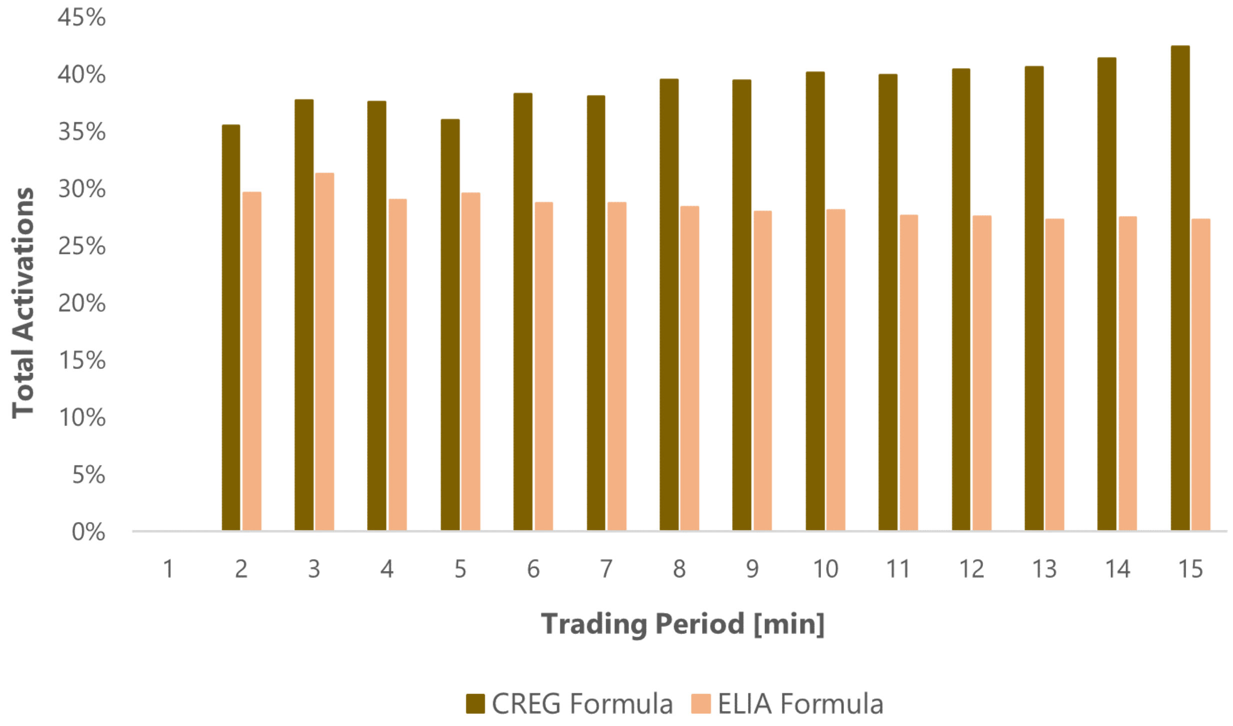




- ❑ Even though the Belgium system is long, upward energy is activated to help the overall long system
- ❑ Belgium price is set due to the activation of upward bids that are submitted either in Germany or in Belgium
- ❑ Long system → ELIA formula provides incentives to <u>not activate</u>

Simulation Results

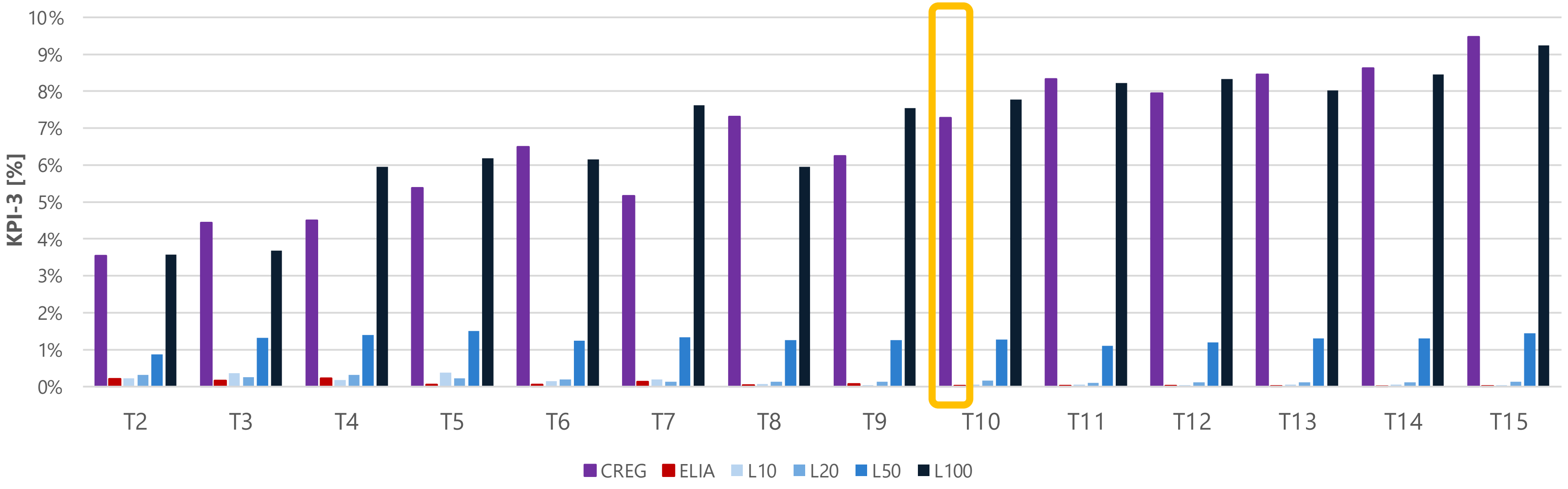
Two-Zone System Analysis – Total Agent Activations



- ❑ **CREG** formula activates the agent more during the end of the interval → activations associated only with the **weighted average price**
- ❑ **ELIA** formula activates the agent less as we move closer to the end of the interval → activations depend both to the **weighted average price** and the **average imbalance**

Simulation Results

KPI-based Analysis – KPI-3 Results

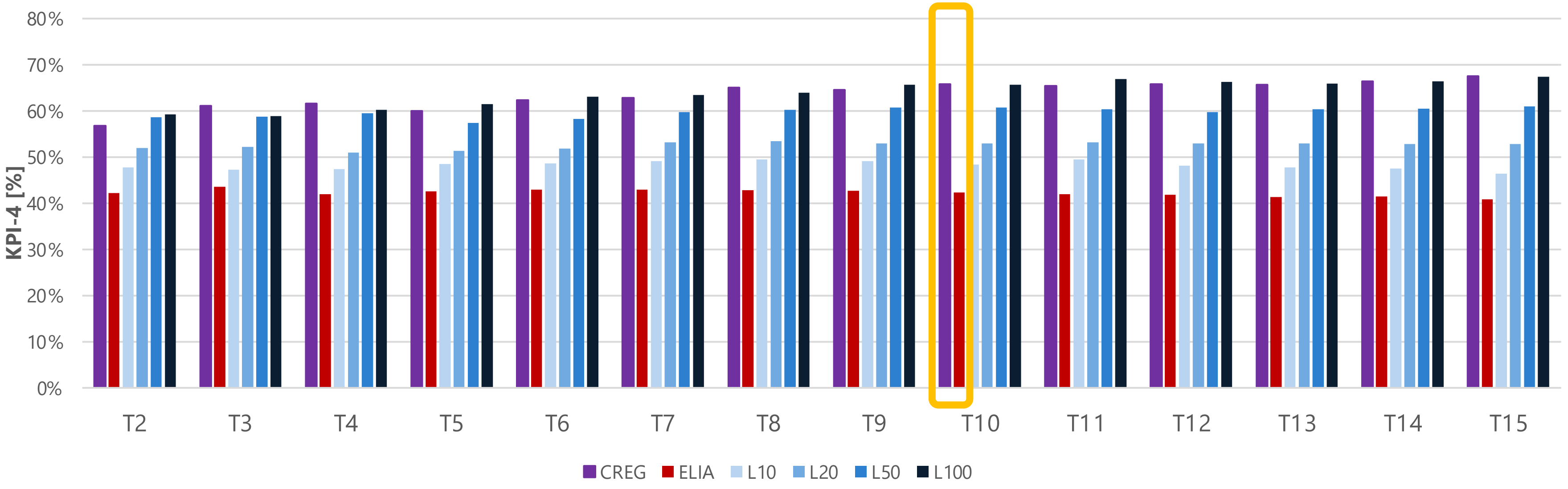


KPI-3: Conditional percentage of time when the interconnecting line is congested in the BE-DE direction and the examined fringe agent opts to increase its production

- ❑ **CREG** formula leads to an increased activation of the agent relative to the **ELIA** one
- ❑ **CREG** formula activates the agent more during the end of the interval but no more than 10%
- ❑ **L50** formula provides similar to the ELIA formula results

Simulation Results

KPI-based Analysis – KPI-4 Results



KPI-4: Percentage of time that the agent is helping the short pan-European system

- ❑ **CREG** formula outperforms the **ELIA** formula → aims at containing the activation of Belgian resources for local imbalances only
- ❑ In the CREG formula the agent is activated more during the end of the ISP interval → agent is reacting to average and not instantaneous conditions

Simulation Results

KPI-based Analysis – KPI-5 & KPI-8 Results

KPI-5: Percentage of time that the interconnected line is congested in the BE-DE direction, the fringe agent is activated, and the downward bid curve in Belgium is depleted

- ❑ Equal to 0% in all minutes of the examined ISP
- ❑ The system is not endangered

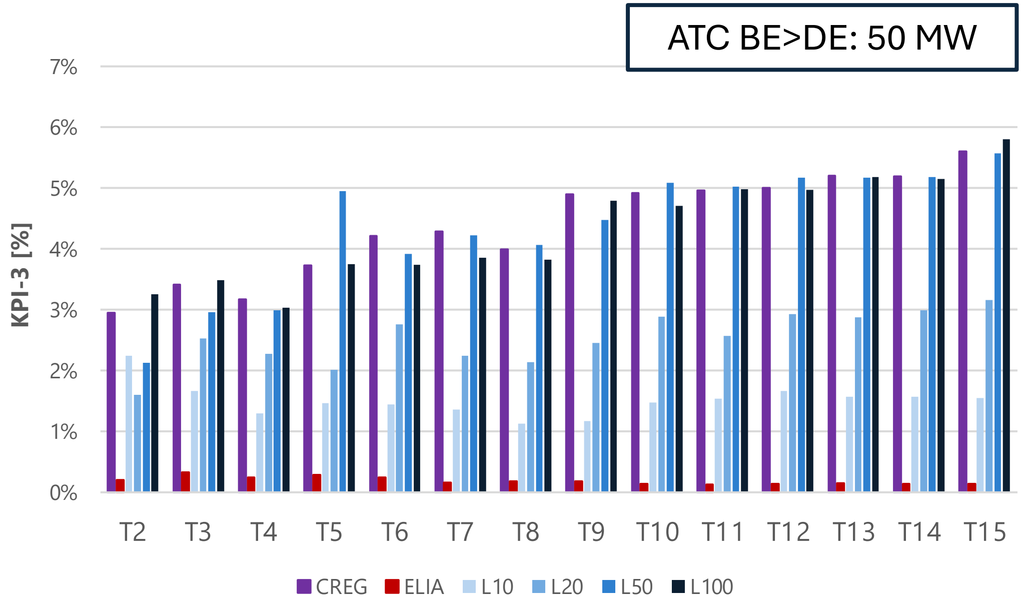
X	30	50	70	90
CREG	0.04%	0.01%	0.00%	0.00%
ELIA	0.12%	0.02%	0.00%	0.00%
L10	0.10%	0.01%	0.00%	0.00%
L20	0.08%	0.01%	0.00%	0.00%
L50	0.05%	0.01%	0.00%	0.00%
L100	0.04%	0.01%	0.00%	0.00%

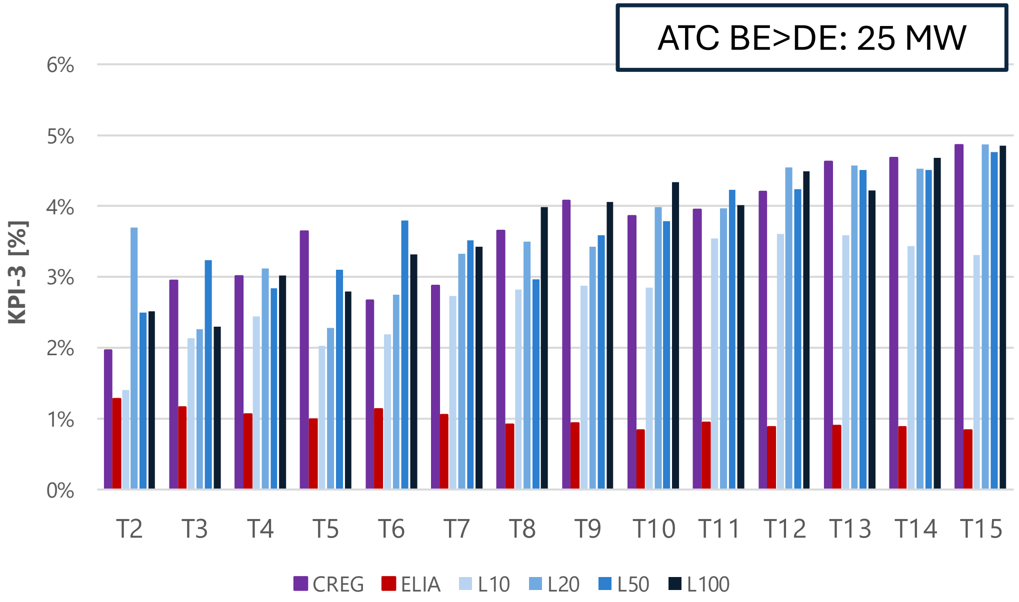
KPI-8: Percentage of time that the agent is activated when the downward cleared quantity is more than X% of the downward bid curve

- ❑ Almost half the downward bid curve is available, even when the agent is activated
- ❑ Overall system security is ensured

Simulation Results

Available Transfer Capacity Effect



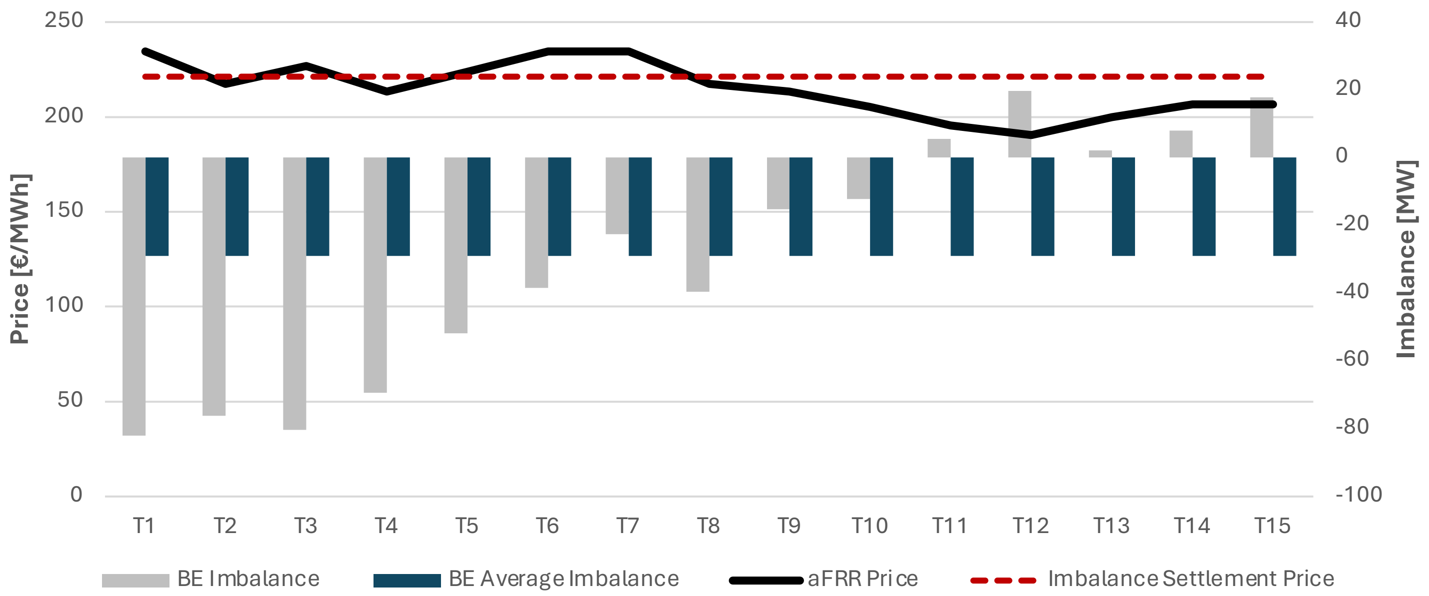


- ❑ Limited available interconnecting capacity
  - ➢ Interconnecting line becomes quickly congested
  - ➢ Long position cannot be exported → activation of downward resources
  - ➢ Low weighted average prices

} Participants avoid self-scheduling

Simulation Results

Imbalance Settlement Period Granularity Effect



Avg. Imbalance: **-28.99 MW**
VoAA Up: **221.24 €/MWh**
VoAA Down: **221.24 €/MWh**
Variable Cost: **212 €/MWh**

CREG Price: **221.24 €/MWh**
ELIA Price: **221.24 €/MWh**

- ❑ Imbalance direction may change towards the end of the imbalance settlement period
- ❑ Imbalance settlement price defined mainly by the price that is derived due to the dominant imbalance direction

- ➢ Arbitrage opportunities from flexible resources that may adapt their output

Conclusions

Policy Conclusions

- Results from extensive simulations demonstrate that:
  - The CREG-based formula may activate the BRPs opposite to the imbalance conditions of the Belgian system → support the needs of the overall European system
  - Belgian system security is not endangered → available downward capacity in the Belgian zone.
  - The ELIA-based formula leads market participants to respond mainly to local imbalances.
  - Additional simulations → for cross-zonal transmission capacity of 100 MW and an imbalance interval of [−50 MW, +50 MW] on which the CREG formula is applied we can achieve similar results to the formula proposed by ELIA. → Combination of the advantages and basic characteristics of both imbalance settlement pricing formulas

Conclusions

Future Directions

- Perform analysis on a multi-area test bed
- Examine additional state-action pairs
- Apply parallel programming to speed-up the training and analysis
- Examine other currently existing European imbalance settlement price schemes

Thank you very much!

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