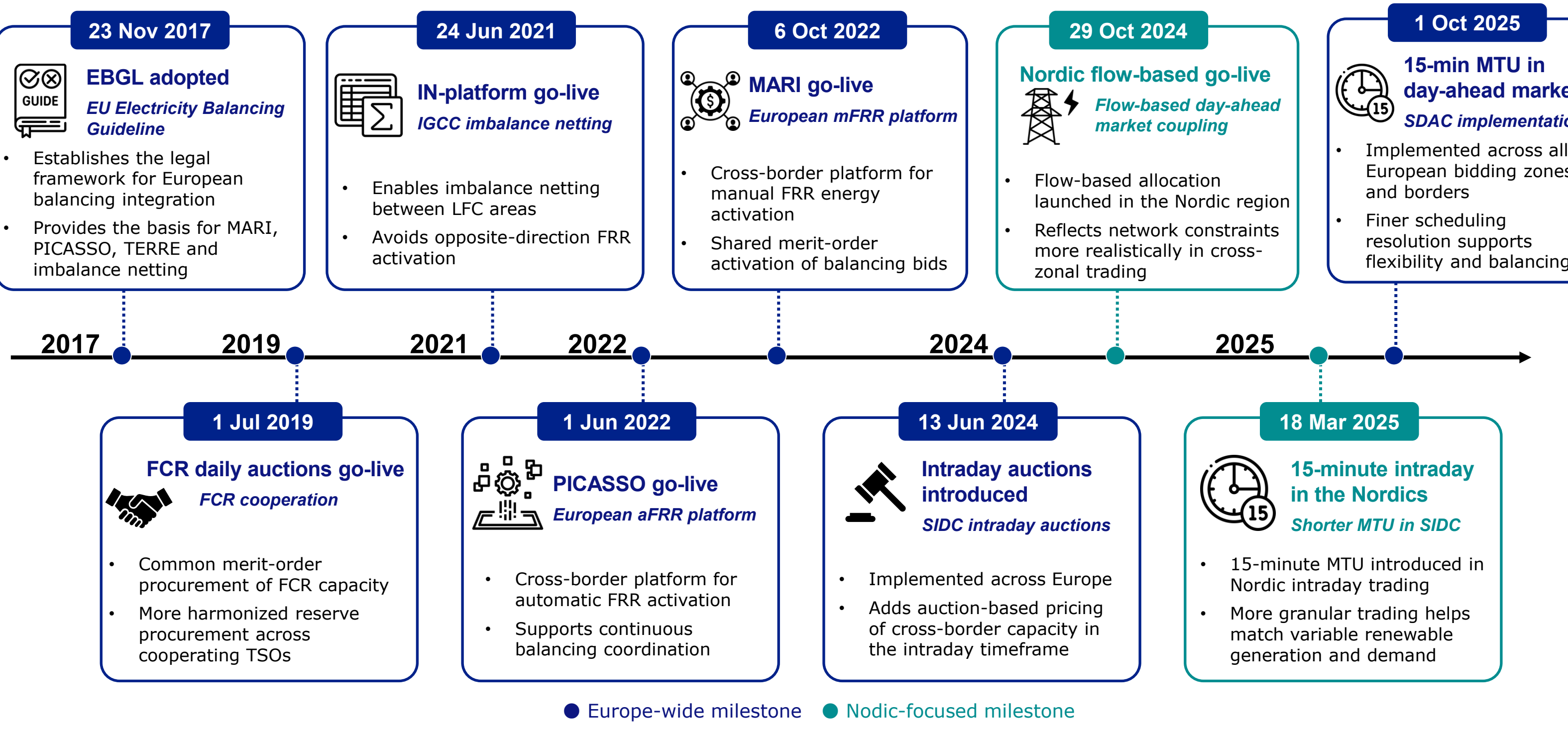


Modelling of power system balancing for future sector-coupled European energy systems

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Recent regulatory developments in electricity markets

In recent years, regulatory developments in Europe have changed the framework conditions for power system balancing by affecting reserve procurement, market time resolution, transmission capacity availability, and cross-border coordination through harmonized platforms.



Research gap and objectives

Future European power systems will rely on high shares of variable renewable energy, increasing the need for flexible resources that can maintain real-time balance between generation and demand. At the same time, balancing markets are becoming increasingly integrated across borders through common European platforms.

- This creates a need for models that can represent both:
- Market integration:** Cross-border activation of balancing energy through platforms such as MARI and PICASSO.
 - Operational constraints:** Transmission limits, reserve availability, activation constraints, and local balancing needs.
 - Future flexibility:** Sector-coupled resources such as heat pumps, hydrogen, batteries, electric vehicles, and storage.

Research objectives

Develop methods for modelling future harmonized and sector-coupled balancing markets with cross-border coordination and activation.

Assess balancing and reserve needs driven by uncertainty in variable renewable energy in a future European energy system toward 2050 across multiple weather years.

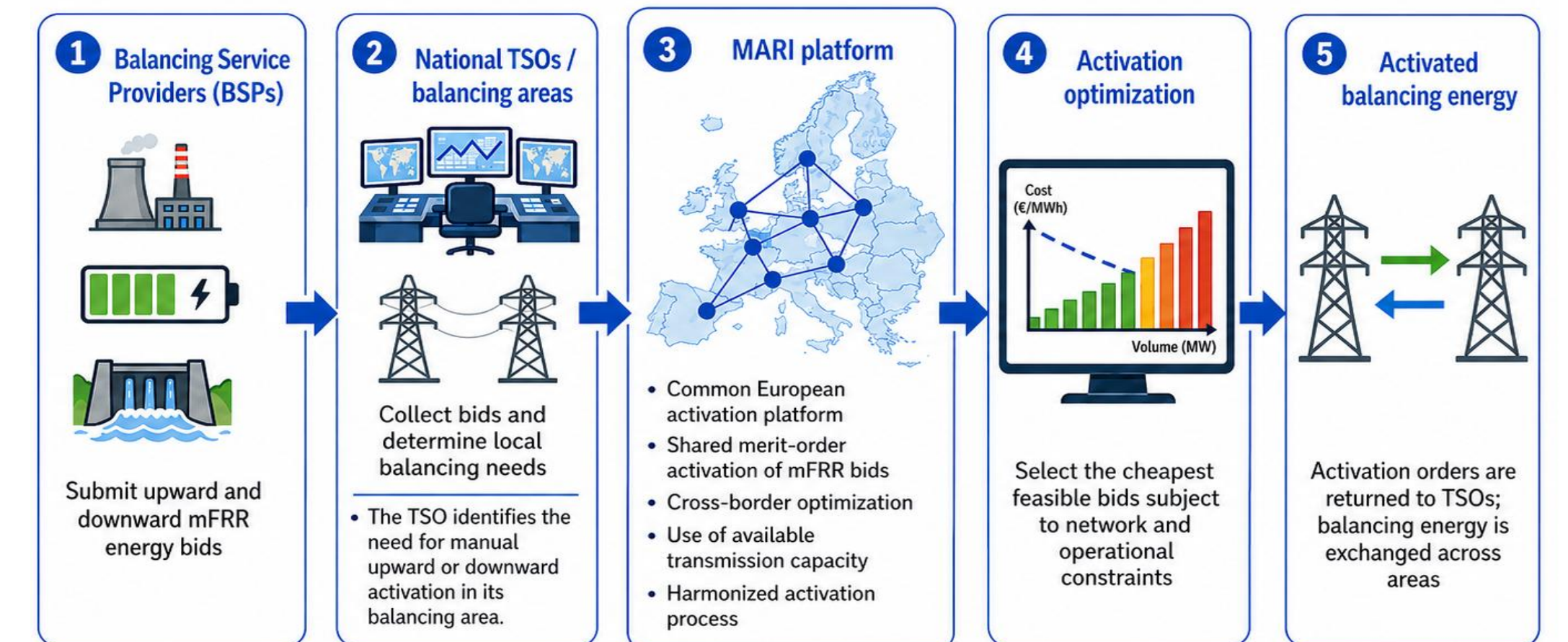
Identify the role of different technologies in providing balancing services in future sector-coupled European energy system.

Harmonization of European balancing markets

Recent implementation of MARI and PICASSO changes balancing from a mainly national process toward a coordinated European market design.

Manually Activated Reserves Initiative (MARI)

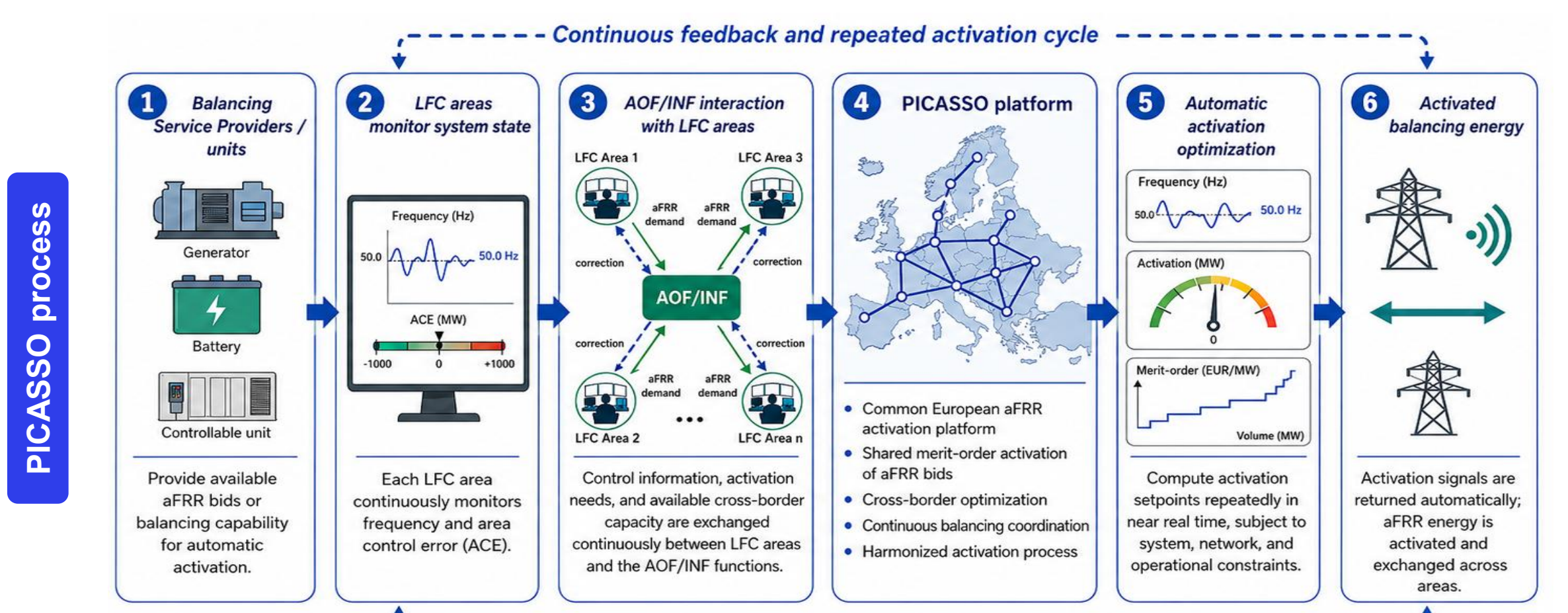
- Manual Frequency Restoration Reserve (mFRR) platform connecting European TSOs for purchasing their mFRR activations.



Key feature: manual balancing energy bids are activated through a common European merit-order platform.

Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO)

- Automatic Frequency Restoration Reserve (aFRR) platform connecting European TSOs for enabling cross-border activation of aFRR balancing energy through automatic frequency restoration coordination.

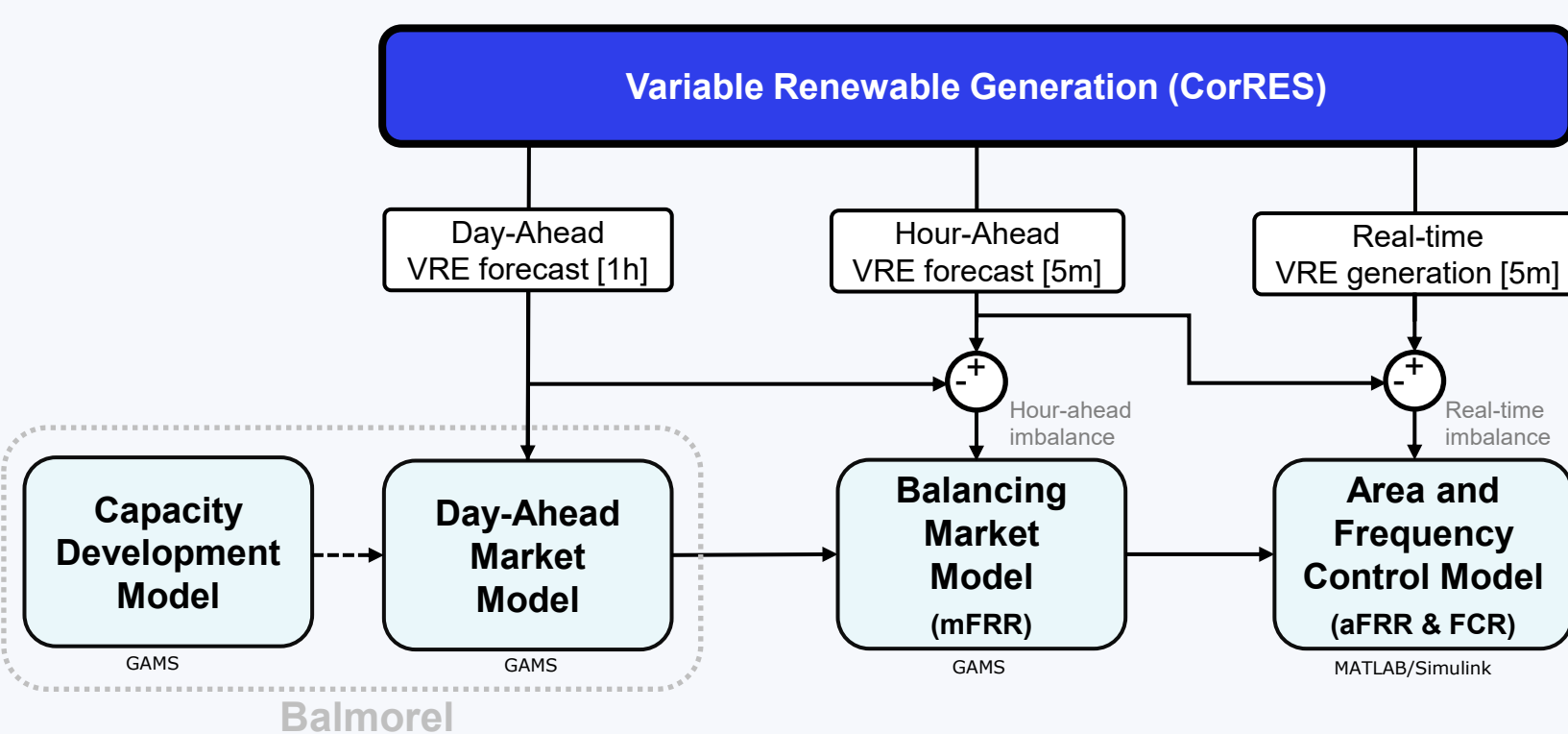


Key feature: aFRR is activated automatically and continuously, with communication and coordination between LFC areas and the PICASSO platform.

Modelling Framework

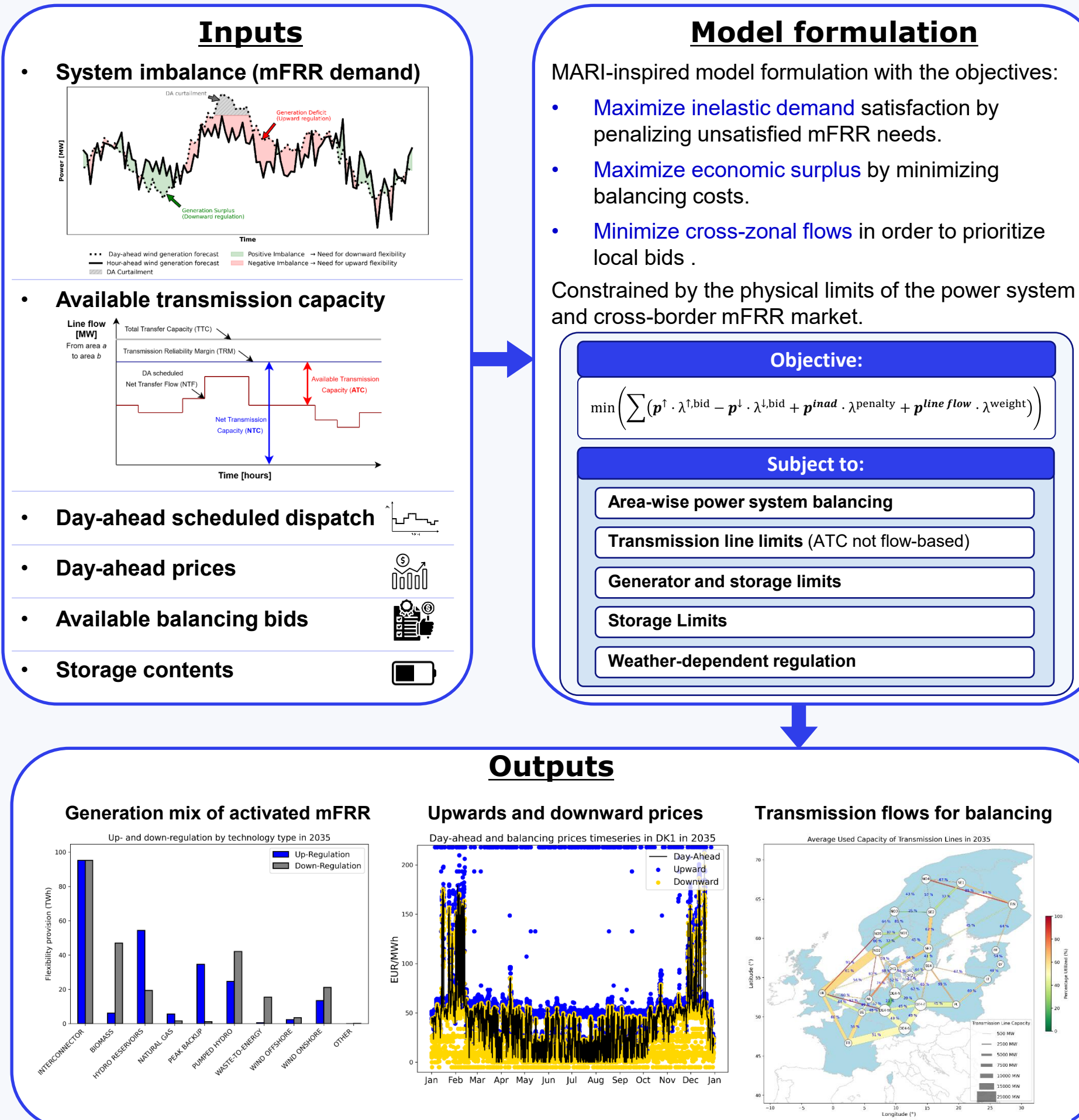
Balancing Tool Chain

The balancing tool chain (BTC) is a tool for modelling multiple steps of the electricity markets and the balancing processes.

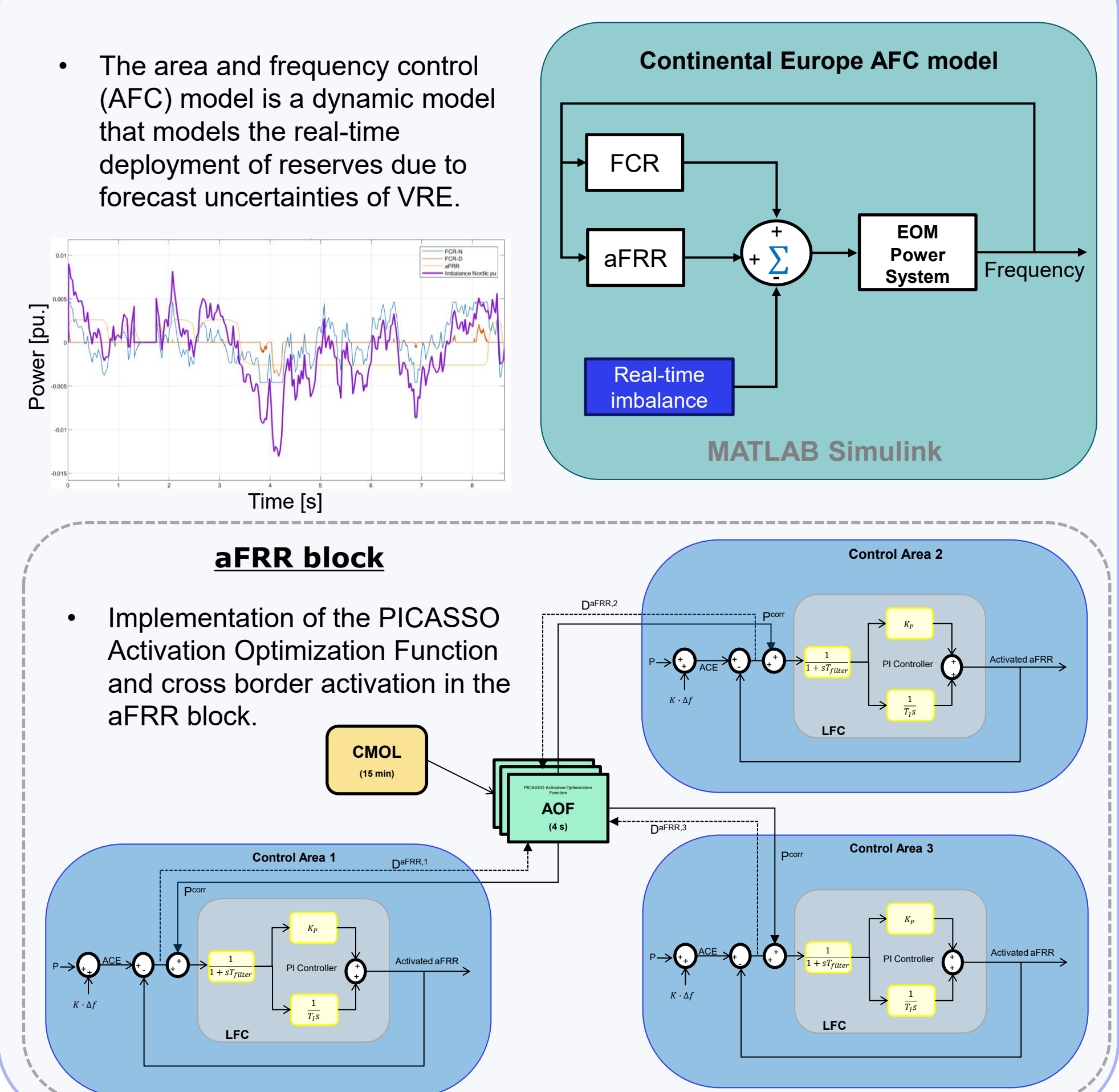


- CorRES**
 - Simulate wind generation and forecasts at different temporal resolutions.
- Balmore**
 - Capacity expansion:** Optimal investments in generation, storage, and transmission capacity.
 - Day-ahead market:** Hourly generation schedules using the day-ahead forecast.
- mFRR balancing market model**
 - Determines the net hour-ahead imbalances caused by forecast errors and re-optimizes the dispatch of flexible units.
 - Modelling mFRR energy activation (MARI).
- Area frequency control model**
 - Simulates frequency deviations and reserves deployment to maintain grid stability in real-time.
 - Modelling aFRR (PICASSO) and FCR activation.

mFRR Balancing Market Model



Area and frequency control model



Next steps

- Solar forecasts**
 - Integrate solar forecasts errors in the BTC framework
- Validation of model**
 - Validation of mFRR market model compared to historical data
- Multiple weather years**
 - Run mFRR model for multiple weather years and assess effect of harmonizing mFRR balancing markets
- PICASSO AOF**
 - Improve model to correctly reflect PICASSO principle and aFRR activation
- Sector-coupling**
 - Developing methodology for sector-coupling to heat and hydrogen in the BTC

Key references

- [1] European Commission. *Establishing a guideline on electricity balancing* (2017).
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