



1158 – Testing TSO-DSO Interactions Schemes for the participation of Distribution Energy Resources in the Balancing Market: The SmartNet Simulator

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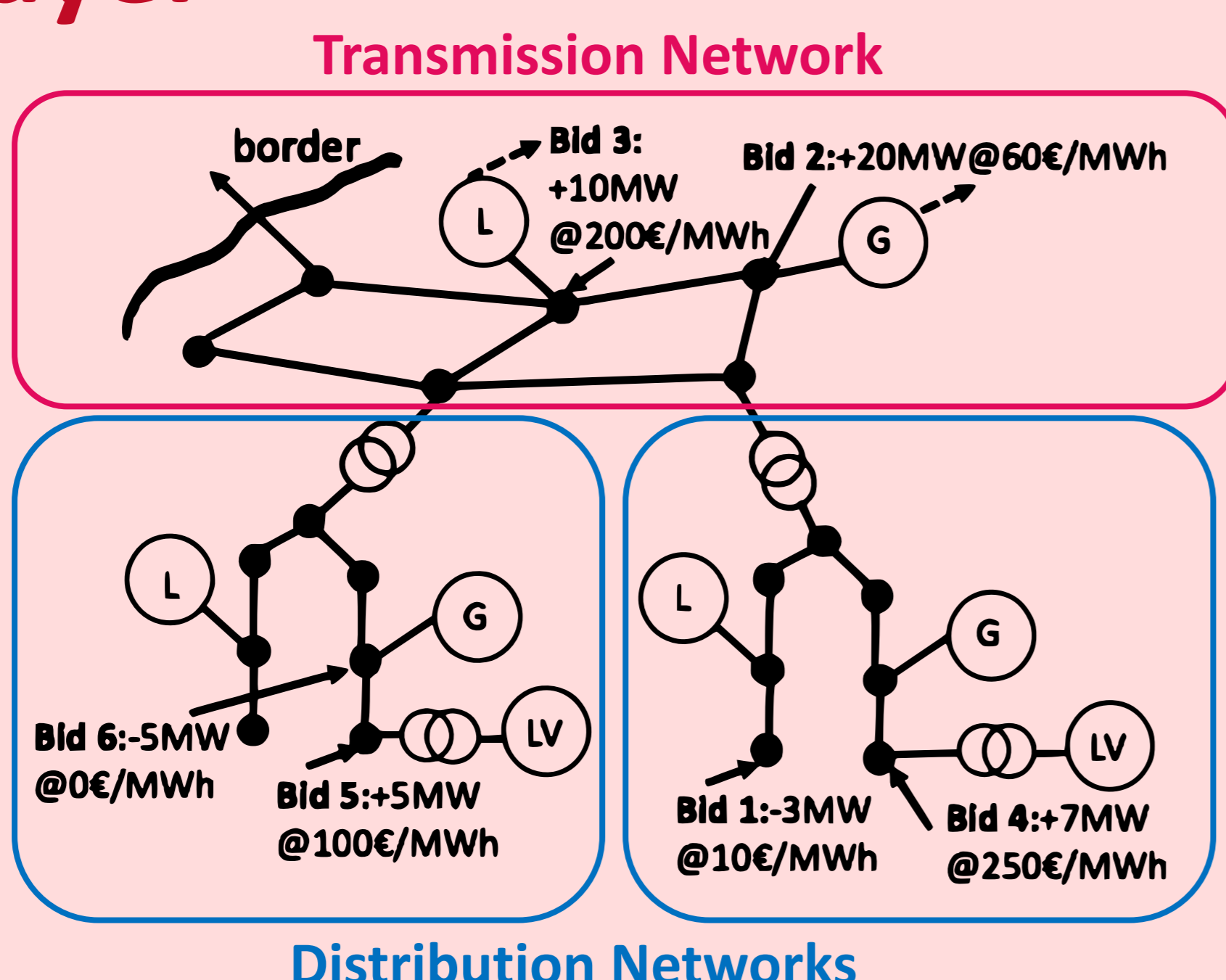
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Market layer

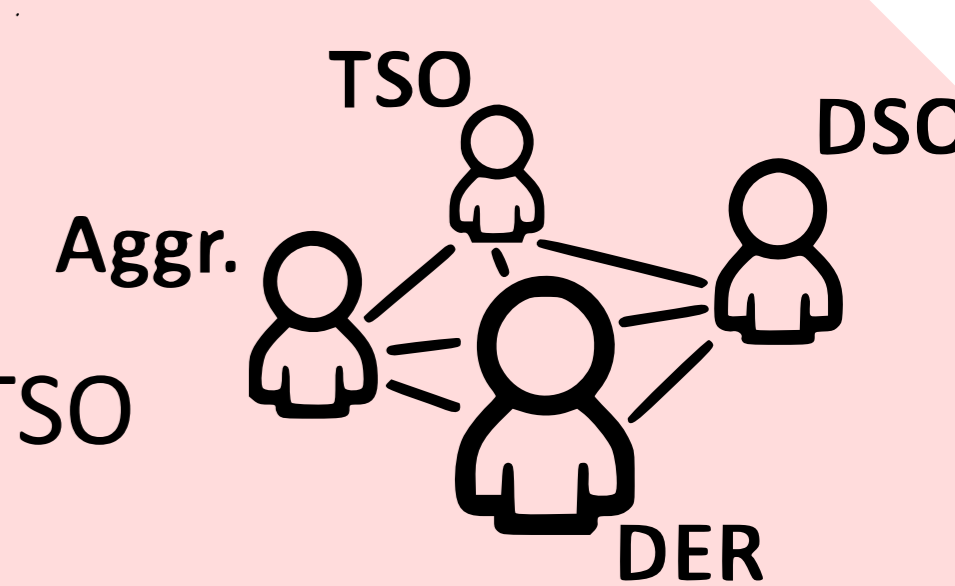
Mixed Integer Linear Programming
(DC Optimal Power Flow)

Mixed Integer Linear Programming
(simplified Dist-Flow Optimal Power Flow)



TSO-DSO coordination schemes

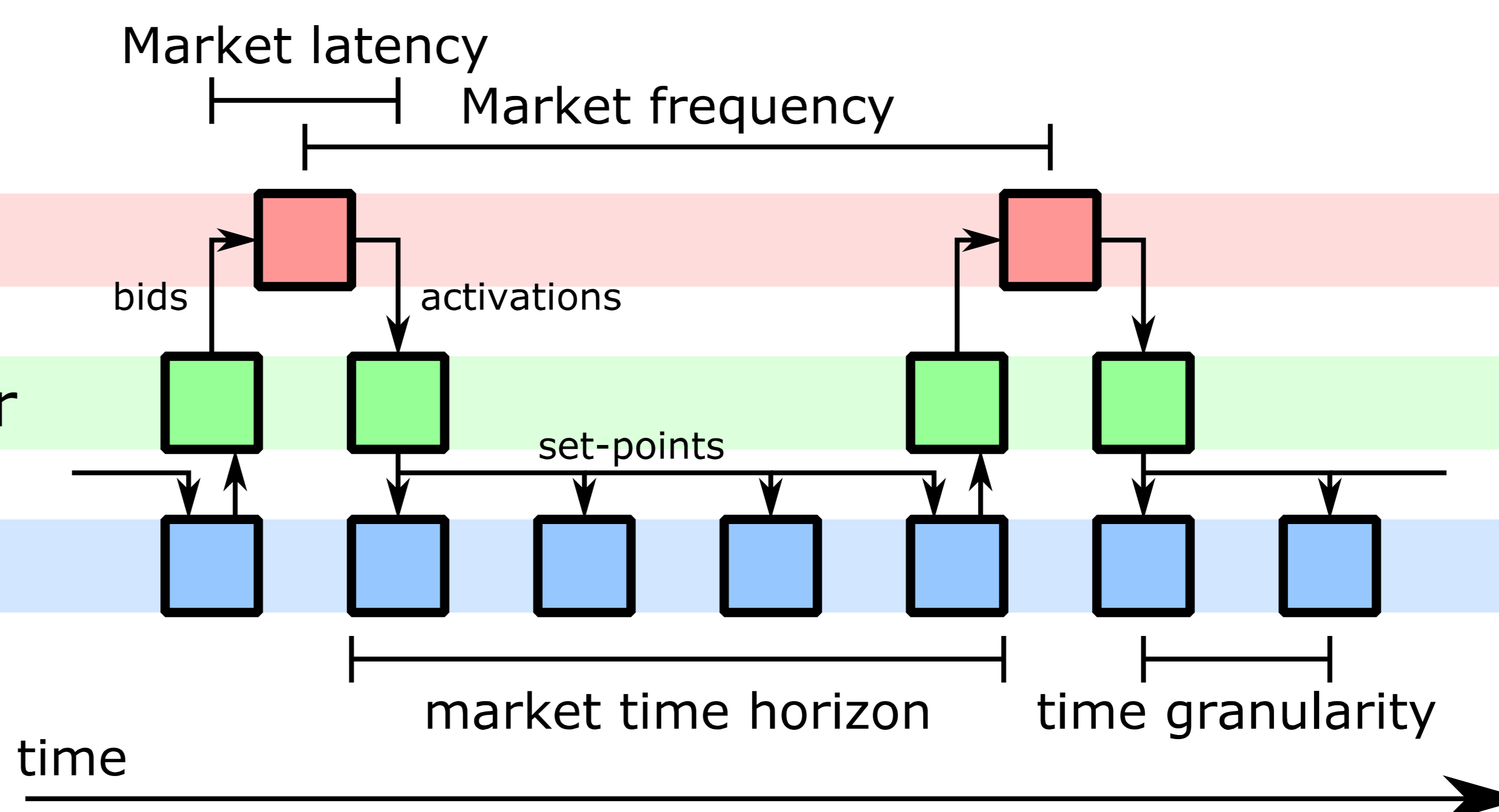
- Centralized ancillary services market
balancing and congestion management services for TSO
- Local ancillary services market
locally prioritized congestion management services for DSO
- Shared balancing responsibility
separated balancing + congestion management services for DSO and TSO
- Common TSO-DSO Ancillary services market model
unified balancing and congestion management for DSO and TSO



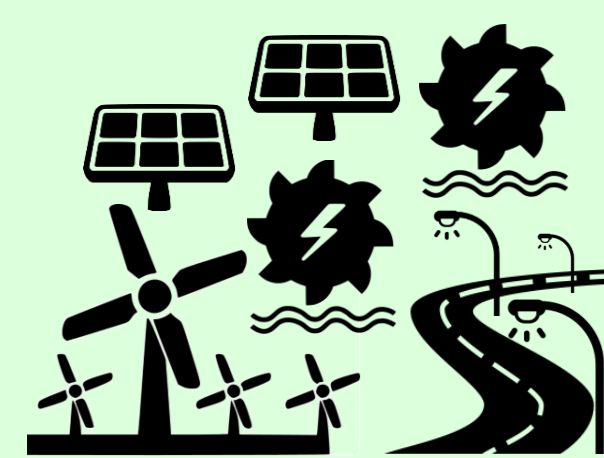
Market layer

Bidding and dispatching layer

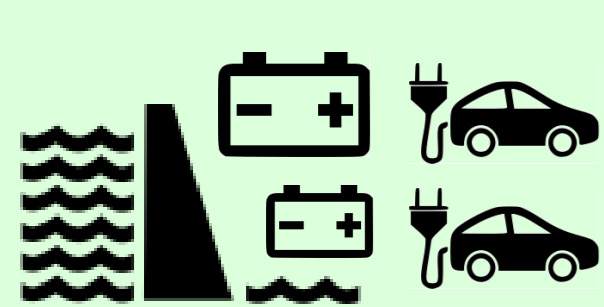
Physical layer



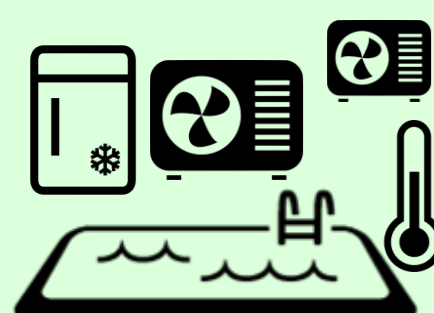
Bidding and dispatching layer



Curtailable generators and loads
Multi-agent based aggregation



Storage-based technology
Optimization based aggregation with energy availability constraints



Thermostatically controlled loads
Equivalent-thermal-model aggregation



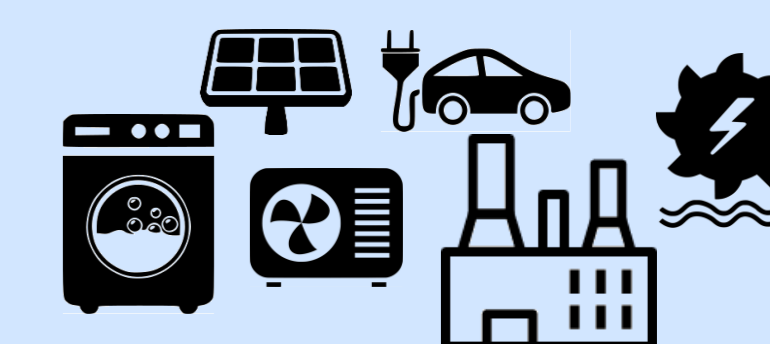
Atomic loads
Integer programming based aggregation



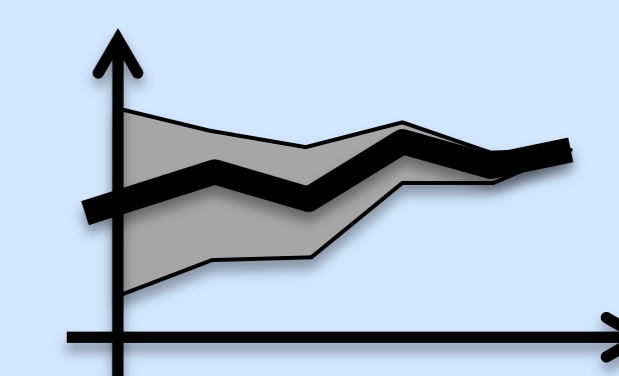
Conventional generators and CHP
Conventional bidding strategy

Physical layer

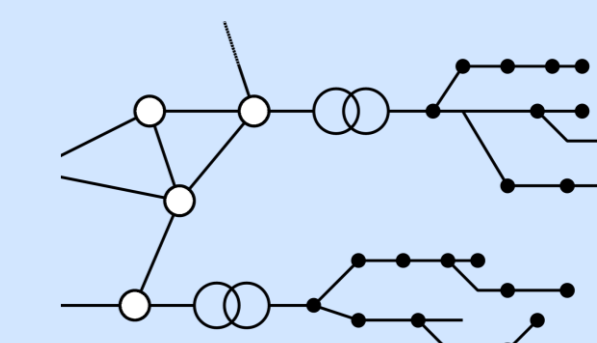
Simulation of flexible units
Zero- and first-order dynamic models



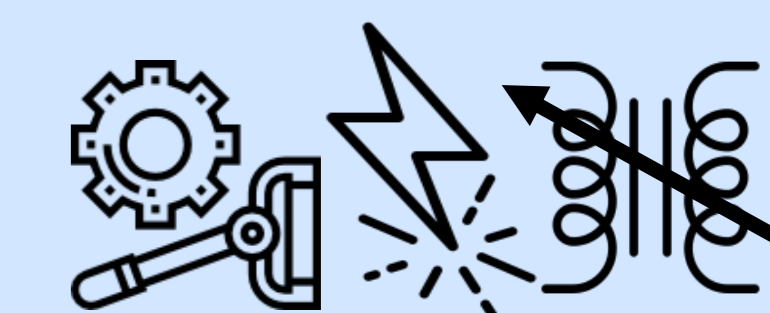
Time evolving forecasting error
Forecasting error is reducing with the proximity to real time



Transmission and distribution networks simulation



Low-level network operations
Response of automatic controllers, emergency actions, re-dispatching (unwanted measures)



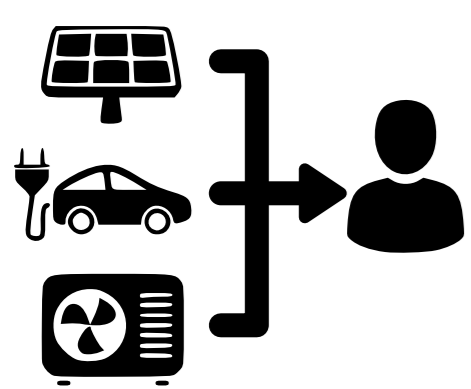
Automatic Frequency Restoration
Activation of aFRR for the management of residual imbalance after market and network operators actions



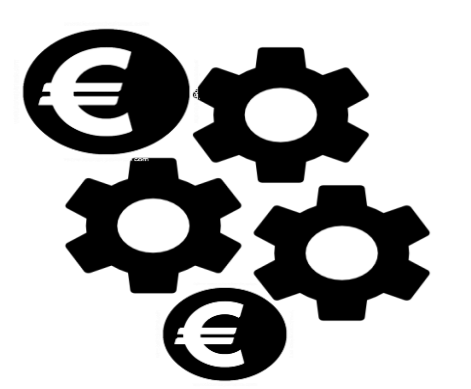
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Detailed sequence diagram of the simulation platform

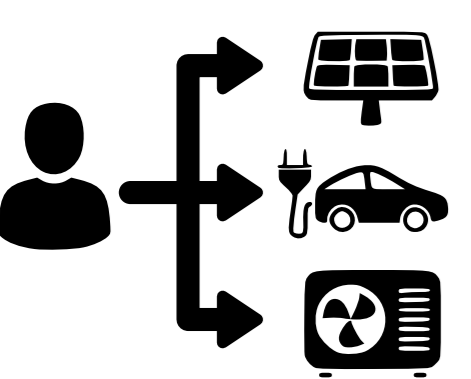
Simulation blocks are processed in sequence and return the status of the network for each time step. On the basis of the assumed market dynamics:



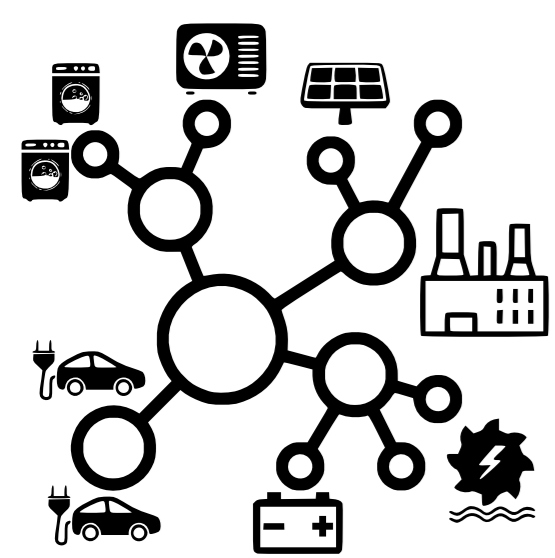
Aggregation routines are launched immediately before the market execution. They bid according to the **forecasted flexibility of resources** for the time steps in which activations will be applied.



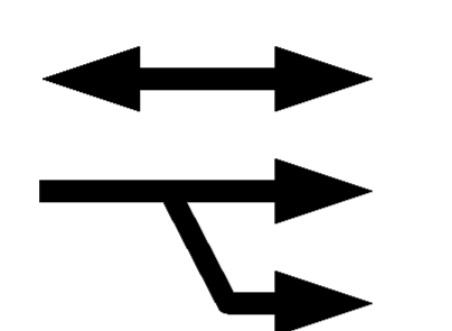
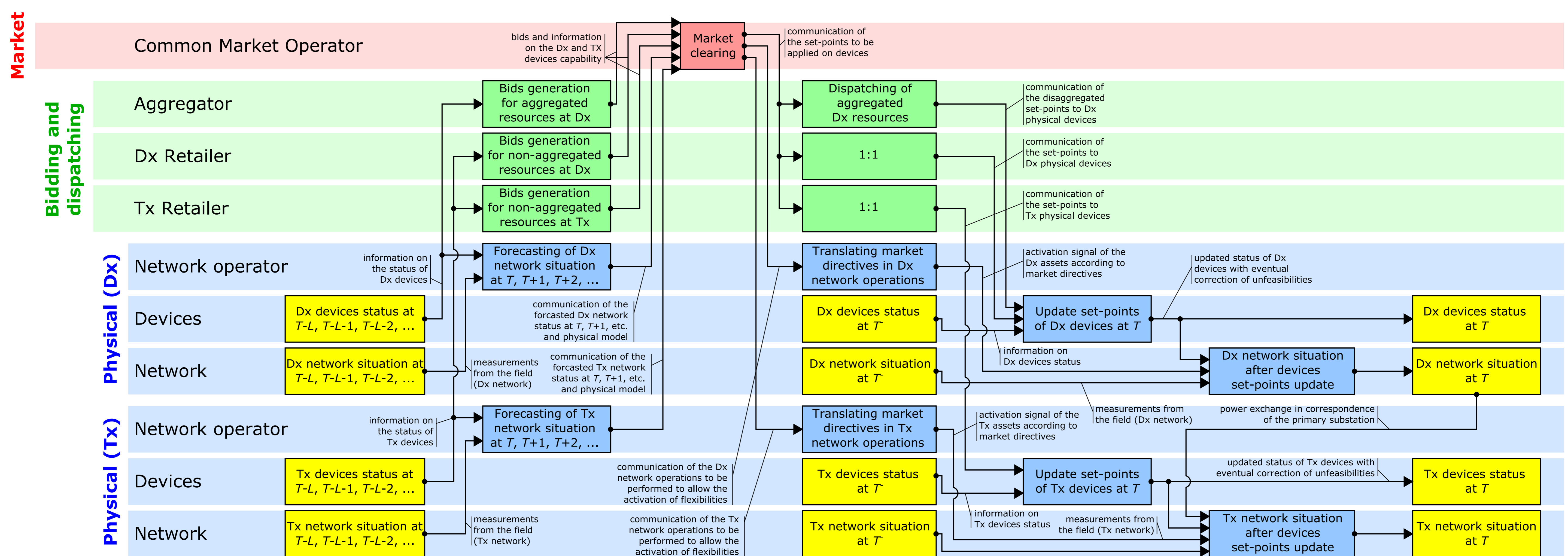
Market routines are executed according to the assumed **market frequency** and returns the clearing results to the (dis)aggregators once the **market latency** has passed. Forecasted imbalance and congestions are used in order to decide the activation over the selected **market time horizon**.



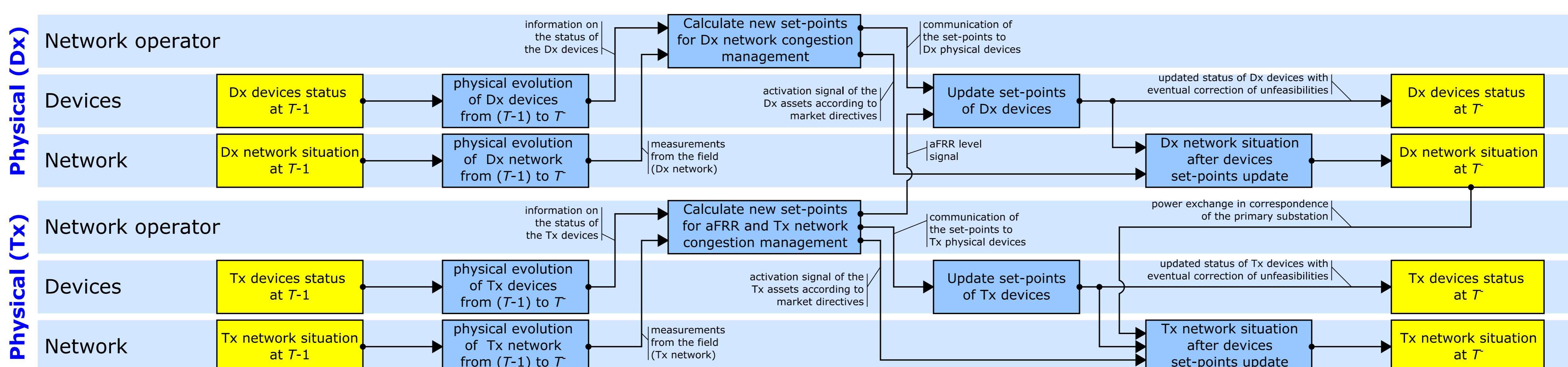
Disaggregation routines process the clearing results and send **individual power set-points** to the aggregated resources.



Physical layer processes the **actual availability of flexible resources** in applying the requested set-points. Transmission and distribution networks are simulated, running also routines aimed at **regulating grid voltage**, **re-dispatching resources** in case of unforeseen congestions, **activating aFRR** in case of residual imbalance.

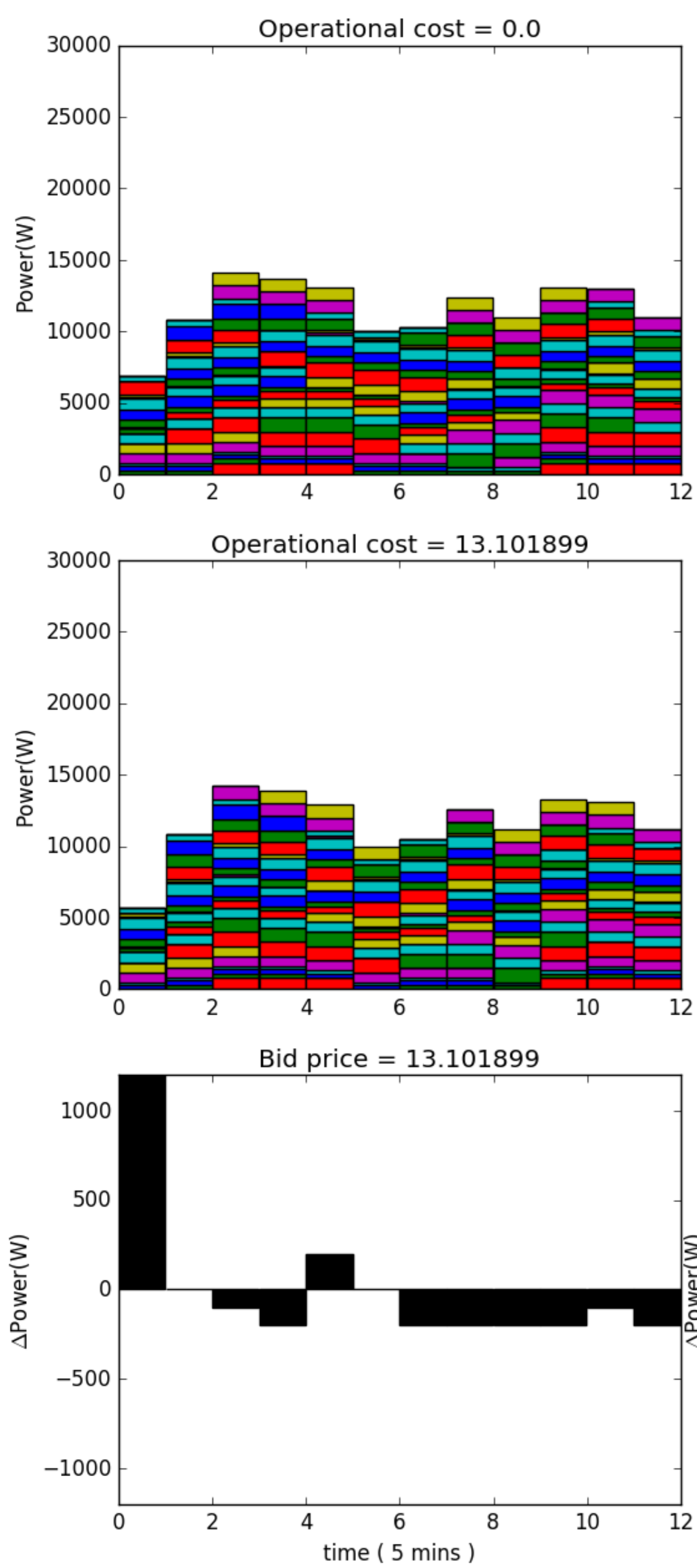


Physical layer also simulates **network evolution during the market clearing process**, time steps in which new bids are submitted already to the market but previous activations still apply.



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Aggregation of Atomic loads



This technique is used to aggregate/dispatch residential appliances such as washing machines and dryers.

These devices can be started at the command of the aggregator, still respecting maximum time delays.

Loads are discrete and non-interruptible, and are joining continuously.

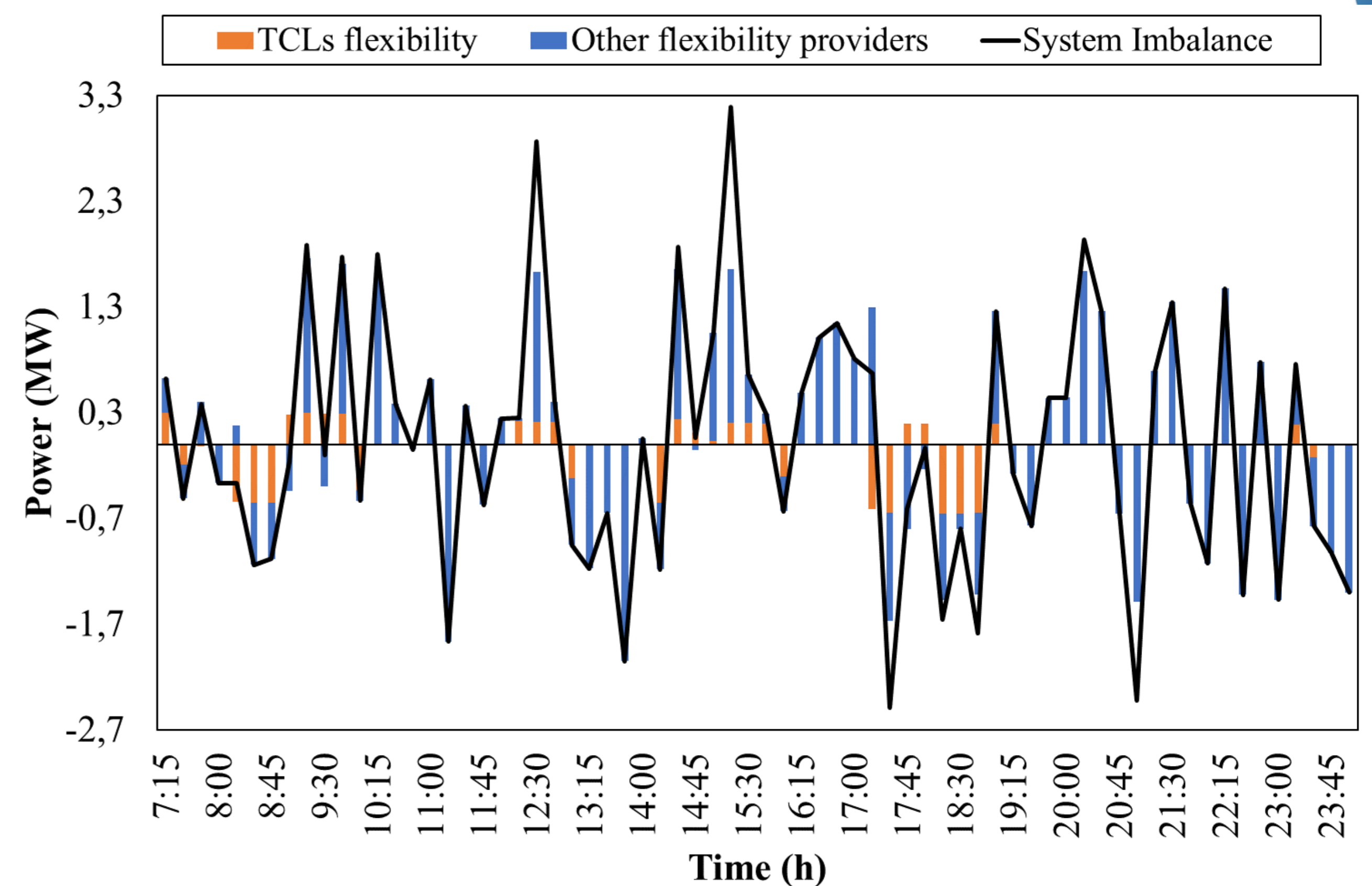
The aggregator is able to control the activation of the loads in order to produce positive or negative flexibility in a given time slot (with minimum rebound effect)



Aggregation Thermostatically Controlled Loads

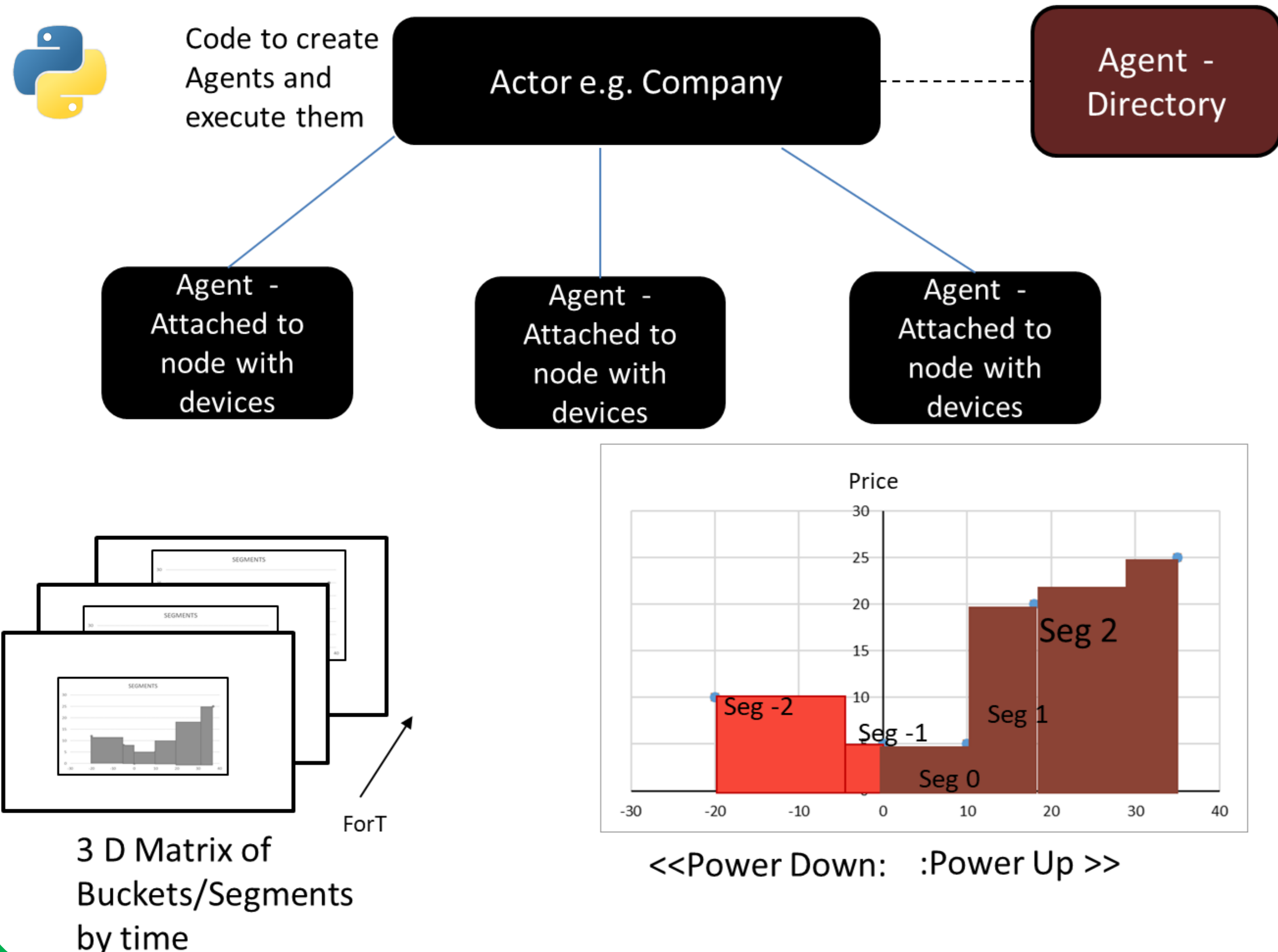
Bottom-up approach for aggregating thermostatically controlled loads, in which flexibility is estimated by using thermal models and measurements collected from the aggregated devices.

The bidding is operated by considering the difference between comfort and temperature set-point (discomfort cost), having considered also rebound effects.



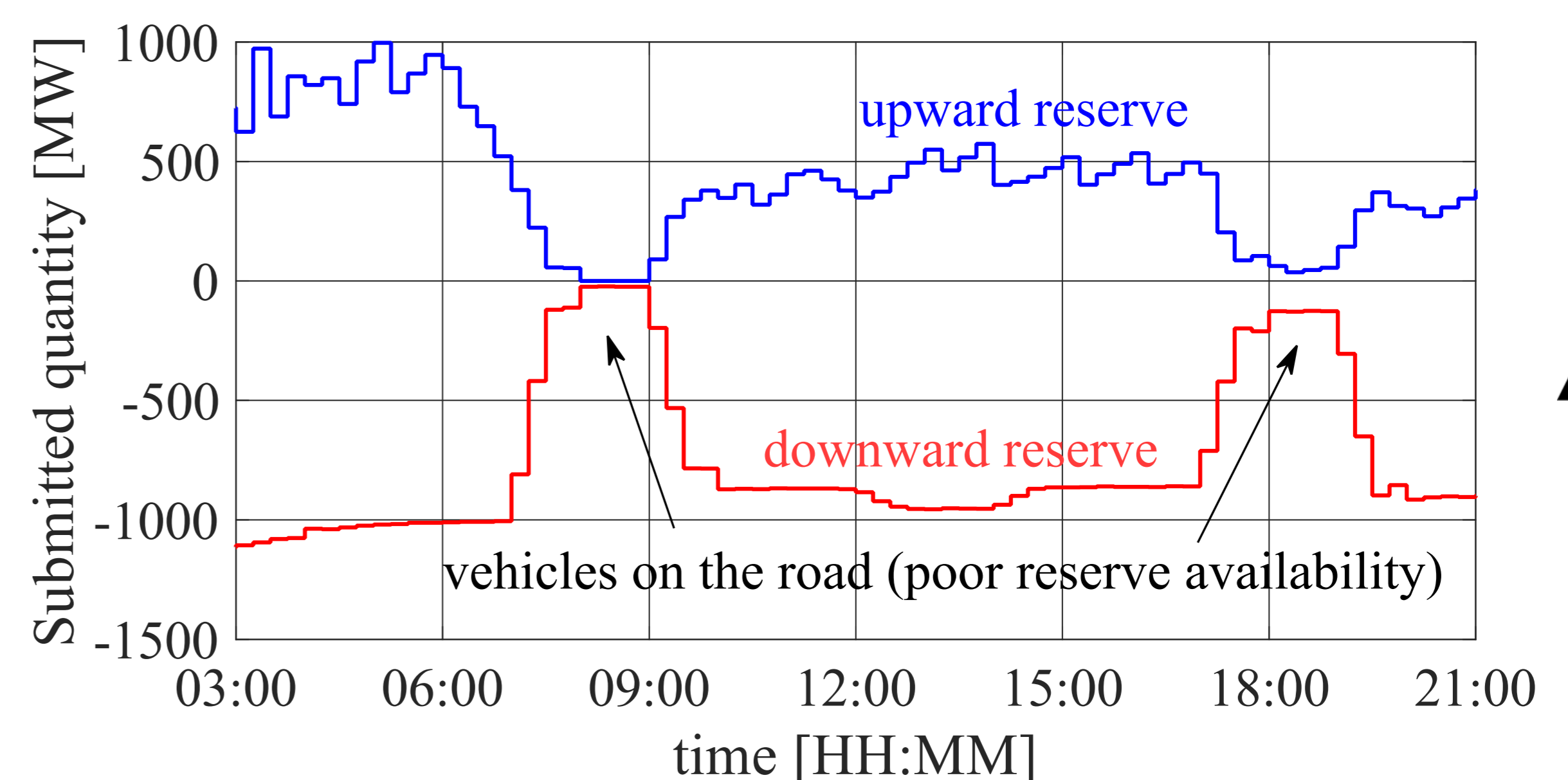
Aggregation of Curtailable Generators and Loads

Multi agent aggregation/disaggregation of curtailable generation (Solar, Wind & Hydro) and sheddable loads without rebound effects (e.g.. street lamps). Uses a novel financially inspired buckets approach, to aggregate thousands of devices into upward and downward flex bids.



Aggregation of Storage-based devices

The model aims at maximizing the aggregator's profit, subject to device specific physical constraints. The degradation costs of EV batteries and market discomfort costs are precisely modeled. The developed model enables the aggregator to manage both stationary storages and EVs.



In contrast, the disaggregation model is a cost minimizing optimization problem, where the main objective consists of supplying the accepted charge/discharge quantity with the lowest possible cost.

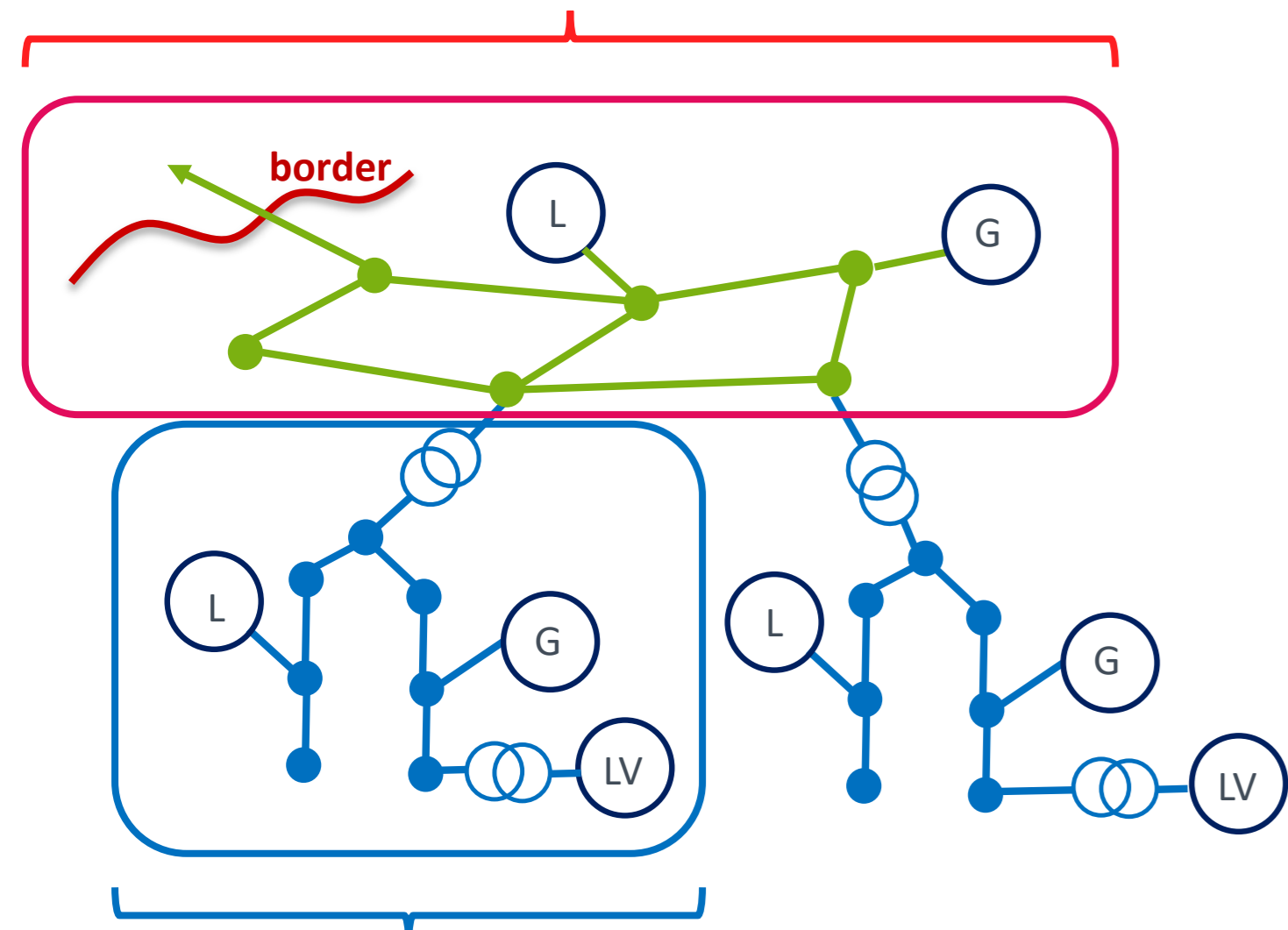
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Market layer

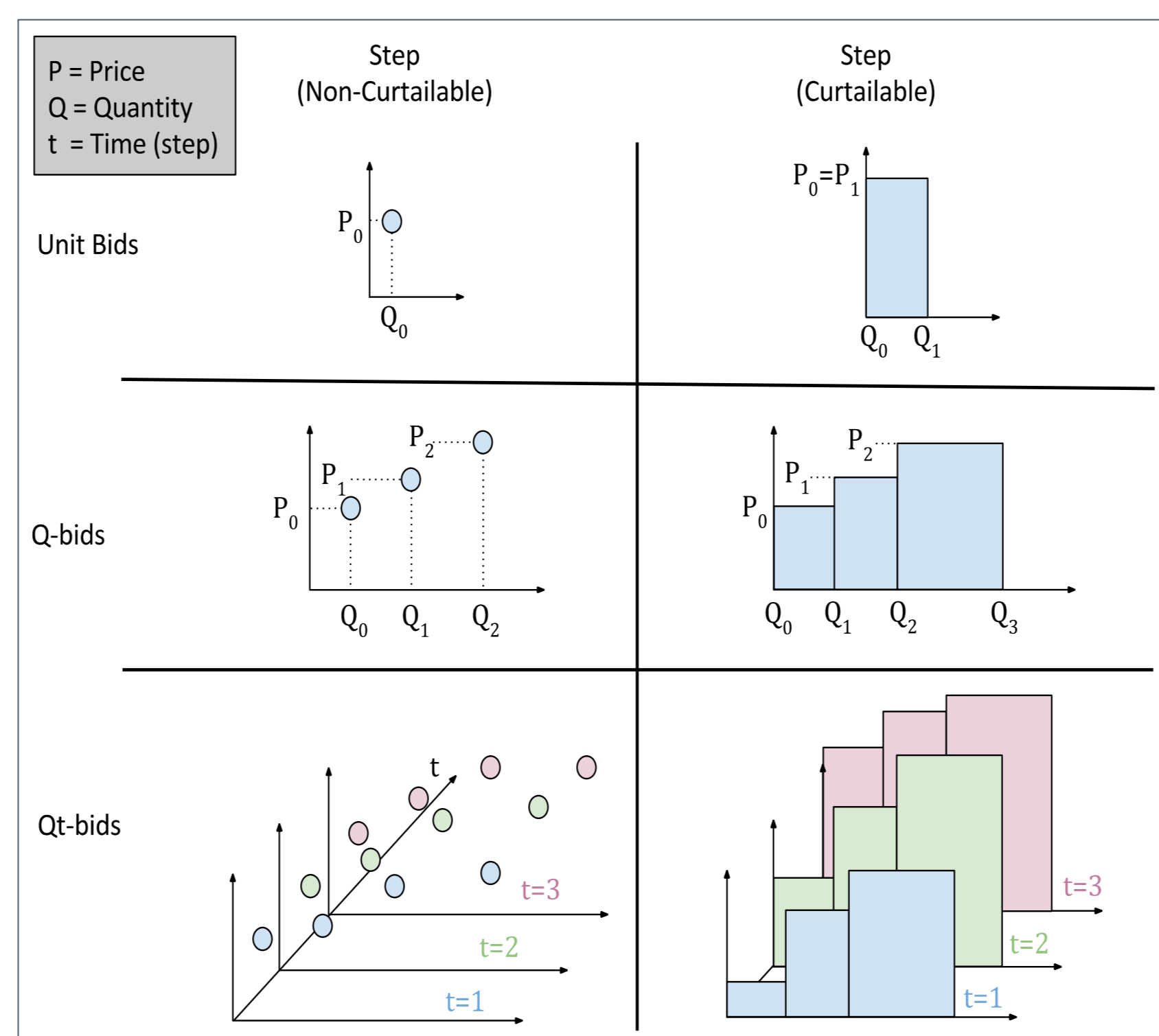
Transmission Network

Traditional **Linear DC approximation**

- **No losses** are modelled
- Voltage angles between neighbours are small
- **No reactive power** notion, **constant voltage** magnitude



Need to choose convex approximations/relaxations in order to guarantee tractability with binary variables



Temporal Constraints

- **Accept-All-Time-Steps-or-None:** → Profile tracking
- **Ramping:** → Turbines
- **Max. number of activations:** → Avoiding wear & tear
- **Max. duration of activation:** → Air conditioning
- **Min. duration of activation:** → Plant efficiency
- **Min. delay between activations:** → Avoiding wear & tear; cool-down and warm-up
- **Integral:** → Electric storage

Logical constraints

- **Implication:** → Series factory lines
- **Exclusive Choice:** → Parallel factory lines
- **Deferability:** → Wet appliances

Distribution Network

1. **Second Order Cone model (distflow)**

- Losses are modelled
- **Active and reactive power** are modelled
- Exact solution in many realistic cases
- BUT difficult tuning of optimization parameter**

2. **Linear Ben-Tal relaxation model**

- **Linearized conic constraints**
- Allows efficient MILP warm-start of (commercial) solvers

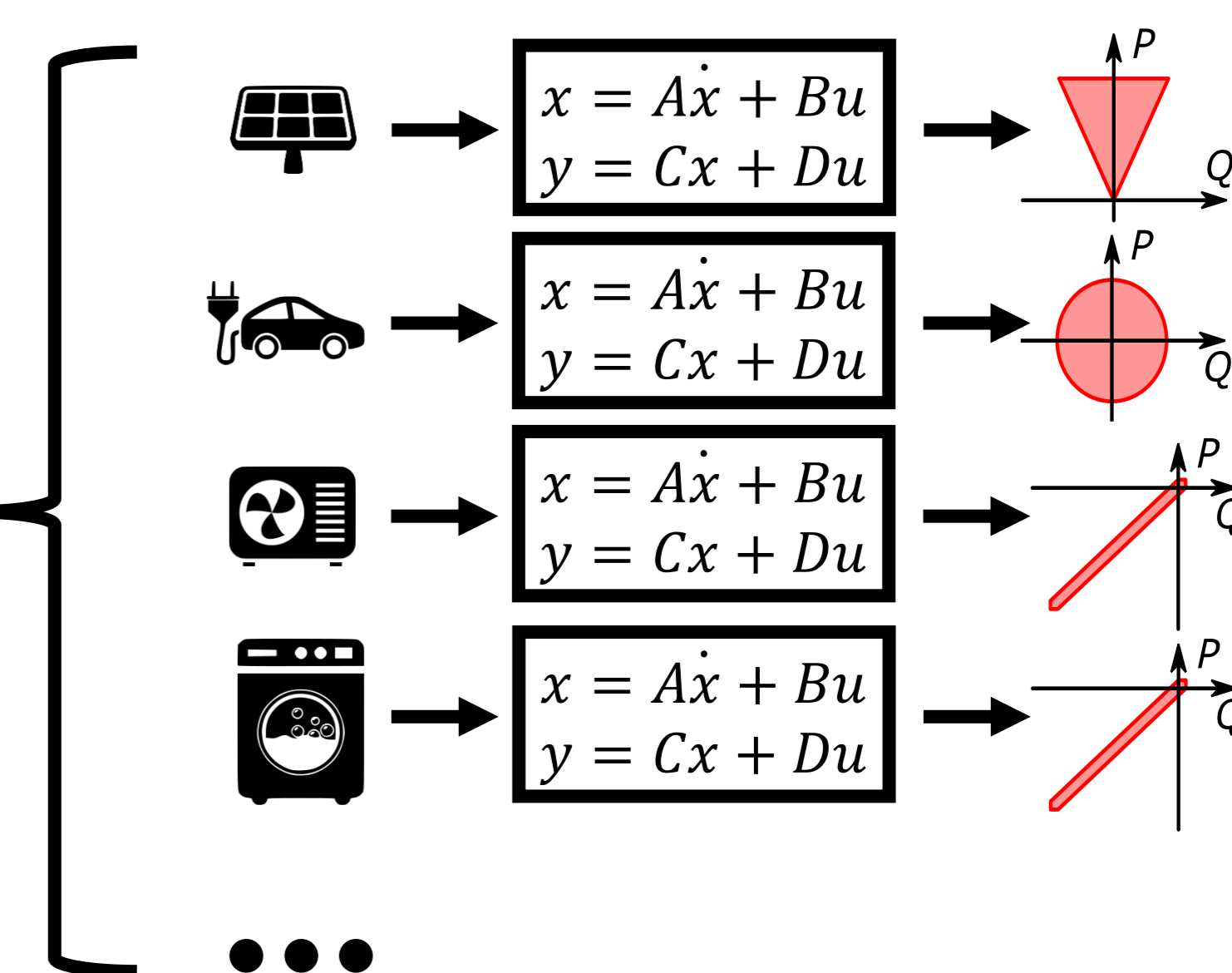
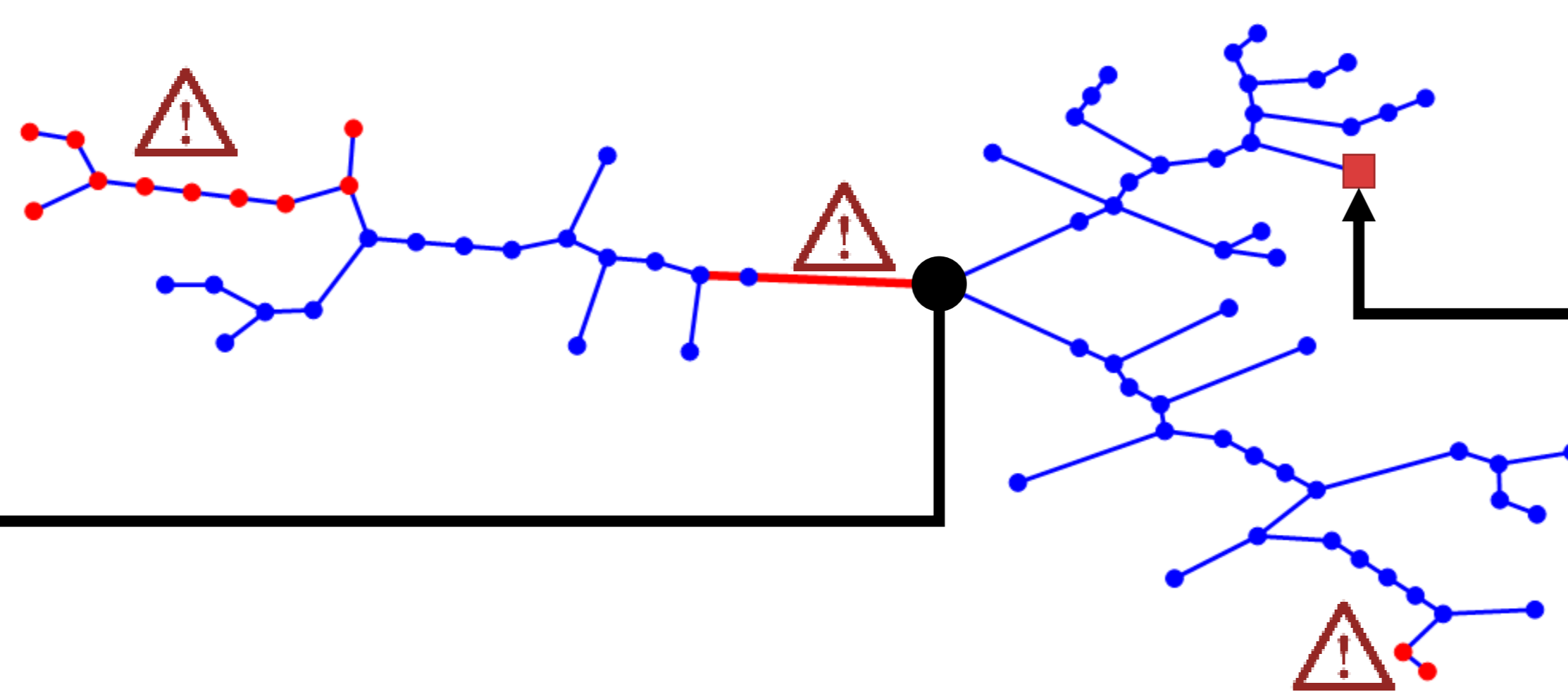
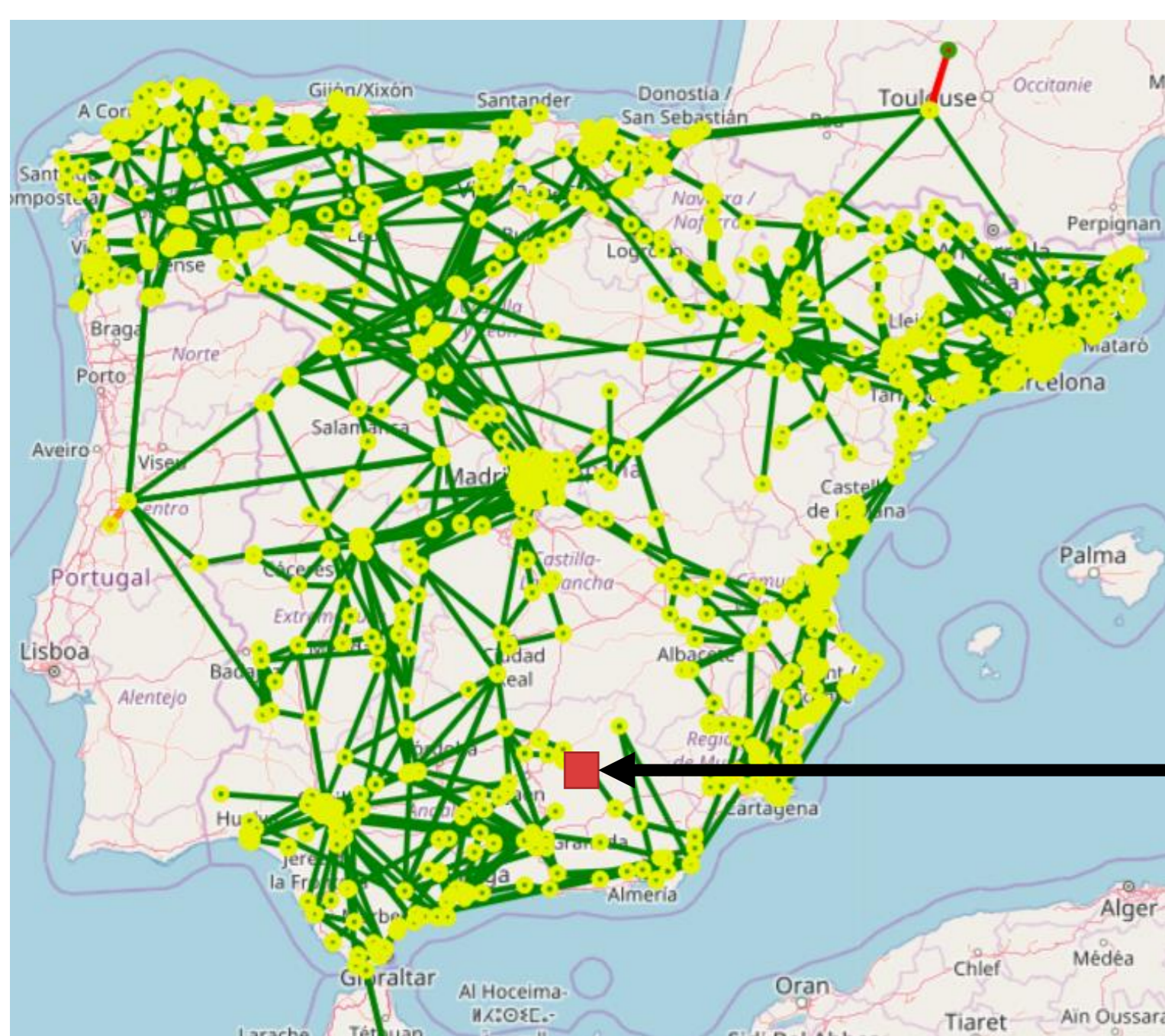
3. **Linear simplified distflow model**

- **No losses** are modelled
- **Active and reactive power** still modelled
- No need to tune optimization parameters

Computational tractability of market clearing algorithm depending on TSO-DSO coordination scheme

Centralized AS market	Common TSO-DSO AS market (centralized)	Integrated flexibility market	Local AS market	Common TSO-DSO AS market (decentralized)	Shared balancing responsibility model
The easiest since only transmission grid	The most difficult since full transmission AND distribution grids in a single problem		Optimizations in parallel BUT with smart aggregation using some complexity		Many optimizations in parallel

Physical layer



Transmission grid simulation

- Collection of power profiles from distribution networks and HV devices
- Conventional AC Optimal Power flow computed for voltage regulation and re-dispatching actions
- Computation of residual imbalance and activations of aFRR

Distribution grids simulation

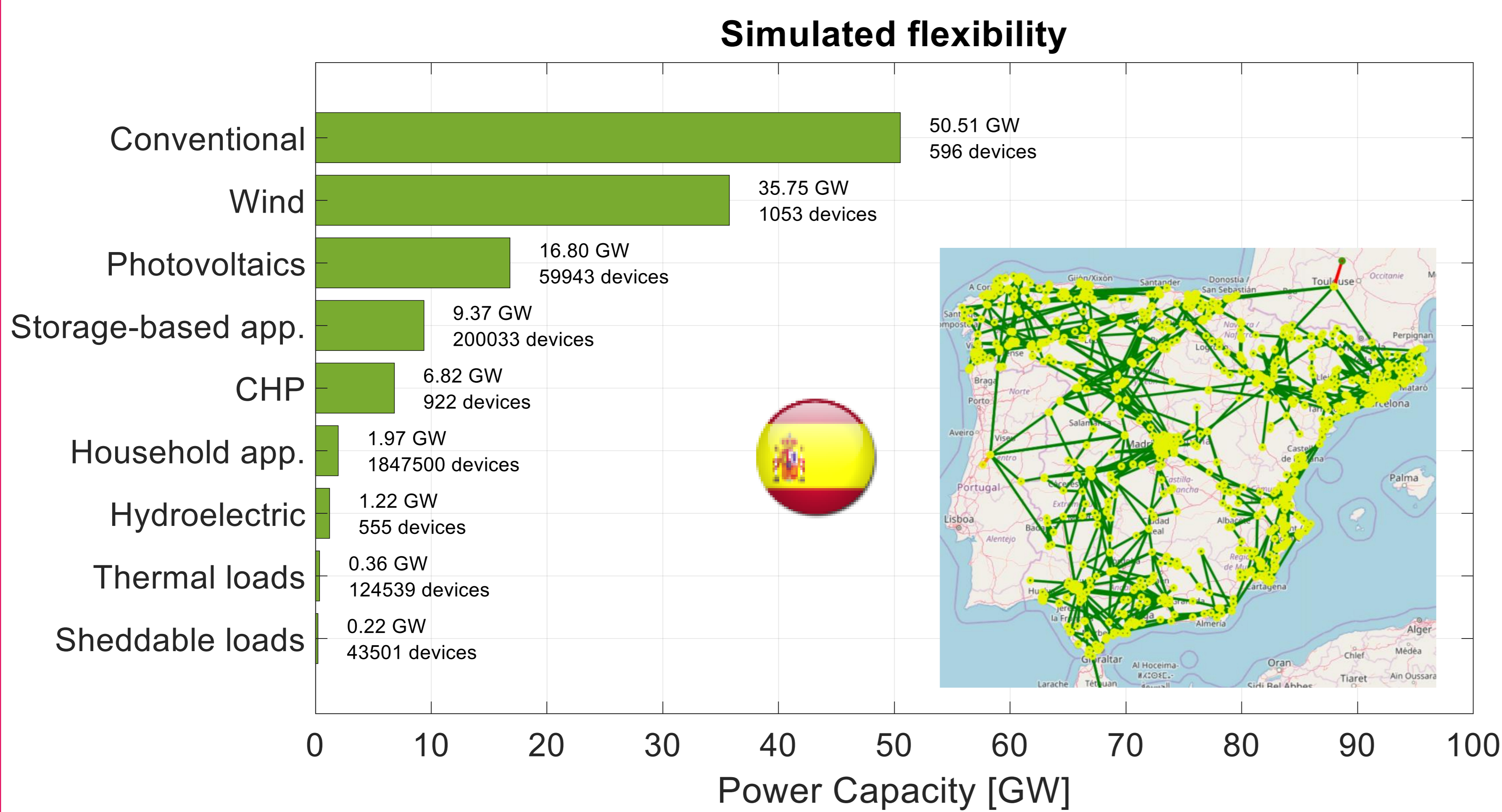
- Collection of power profiles from MV devices (LV networks assumed to be without congestions)
- Conventional AC Optimal Power flow computed for active and reactive power re-dispatching (congestion management)

Flexible devices simulation

- Collection of baseline power profiles and set-points provided by (dis)aggregators
- Zero/first order State-space models adopted for the computation of actual power exchange depending on internal states/variables

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Simulation of the 2030 Scenario (Italy – Denmark – Spain)

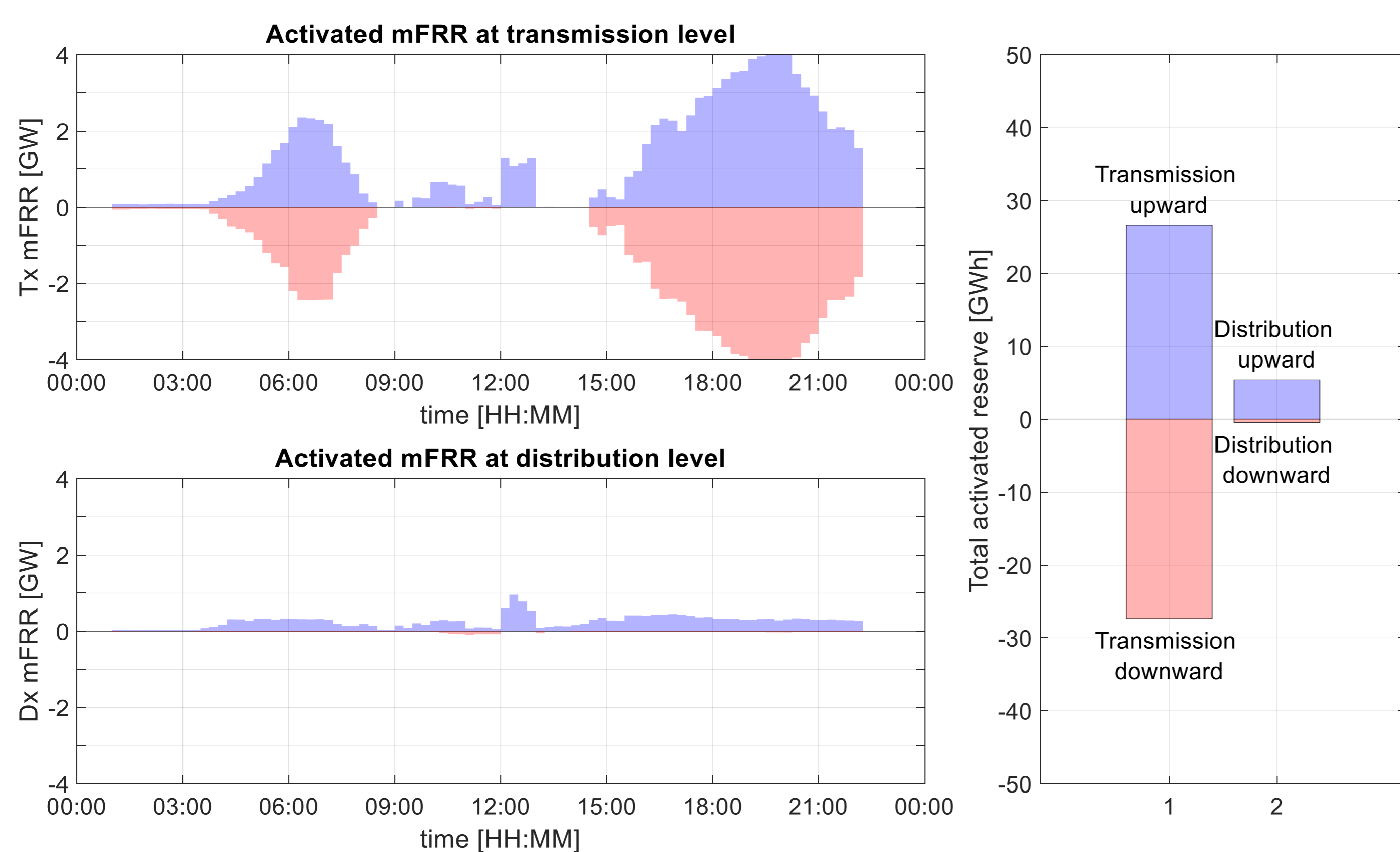


A 2030 scenario for Spain has been hypothesized. With respect to the current situation:

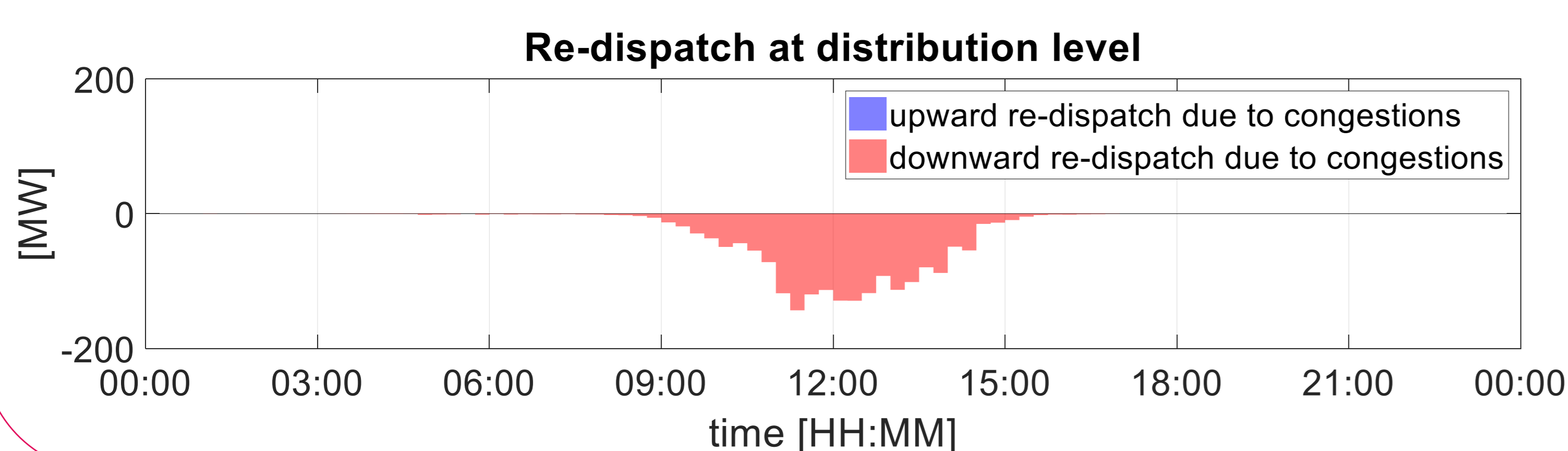
- Significant increase of photovoltaic and wind generation (mostly distributed)
- Thanks to electric vehicles spread, relevant flexibility is expected from storage-based units.

Simulation of TSO-DSO coordination scheme A

Simulation of schemes in which distribution network constraints are not included within market clearing.

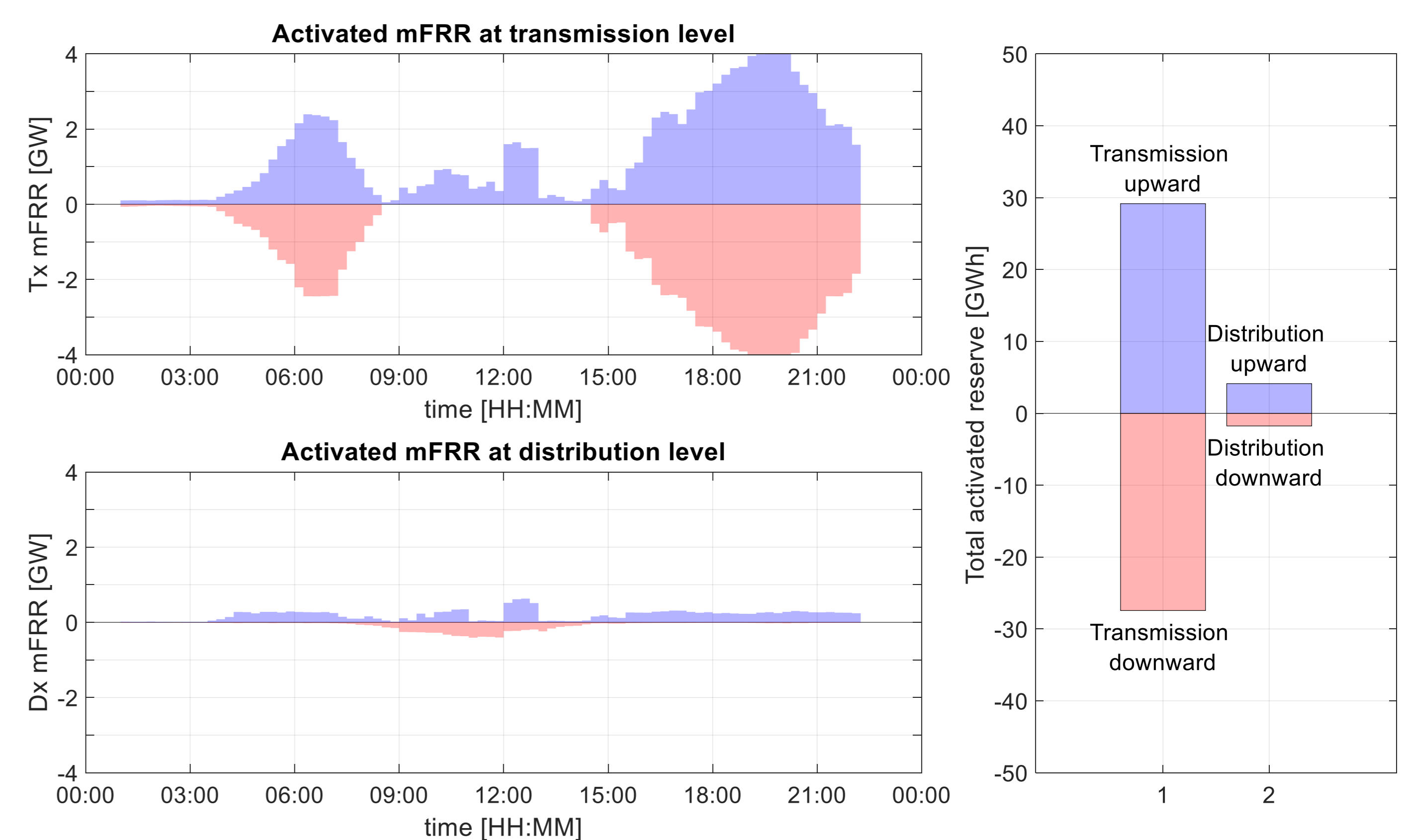


- In case of congestions, both upward and downward mFRR are activated
- Upward mFRR at distribution level is more competitive than transmission network one
- Large volumes of activations need to be re-dispatched because of distribution network congestions



Simulation of TSO-DSO coordination scheme D

Simulation of schemes in which DSO can buy flexibility for congestion management at distribution level.



- The market-level management of congestion at distribution impacts on the activations of flexible resources at this level:
 - Lower distribution upward flexibility is used for providing services to the TSO
 - Downward activations of distribution resources (mostly photovoltaics) are operated in order to solve network congestions.

