Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

IRED 2018 Vienna| 18.10.2018

The SmartNet Project

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405

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Agenda

- The SmartNet project (motivations, set-up, consortium, activities flow)
- Five TSO-DSO coordination schemes
- Proposed AS market design
- The simulation platform
- Balancing market and aFRR
- ICT requirements
- Results for the three simulation scenarios
- Layout of three project pilots
- Regulatory Analysis: work structure

Motivations

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- Increased reserve needs due to explosion of variable RES
- Opportunities from new DER in distribution?
- Five key questions:

Which ancillary services could be provided from entities located in distribution networks	How the architectures of dispatching services markets should be consequently revised
Which optimized modalities for managing the network at the TSO-DSO interface	What ICT on distribution-trans-mission border to guarantee observability and control

Which implications on the on-going market coupling process

"Some actions can have a negative cross-network effect. For instance, TSO use of distributed resources for balancing purposes has the potential to exacerbate DSO constraints. Equally, whilst DSO use of innovative solutions, such as active network management, can deliver benefits to customers, if not managed properly they may in some cases counteract actions taken by the TSO" (CEER Position Paper on the Future DSO and TSO Relationship – Ref. C16-DS-26-04 – 21.09.2016)

Article 32

Tasks of distribution system operators in the use of flexibility

1. Member States shall provide the necessary regulatory framework to allow and incentivise distribution system operators to procure services in order to improve efficiencies in the operation and development of the distribution system, including local congestion management. In particular, regulatory frameworks shall enable distribution system operators to procure services from resources such as distributed generation, demand response or storage and consider energy efficiency measures, which may supplant the need to upgrade or replace electricity capacity and which support the efficient and secure operation of the distribution system. Distribution system operators shall procure these services according to transparent, non-discriminatory and market based procedures.

Distribution system operators shall define standardised market products for the services procured ensuring effective participation of all market participants including renewable energy sources, de operators shall exchange all n system operators in order to e secure and efficient operatio

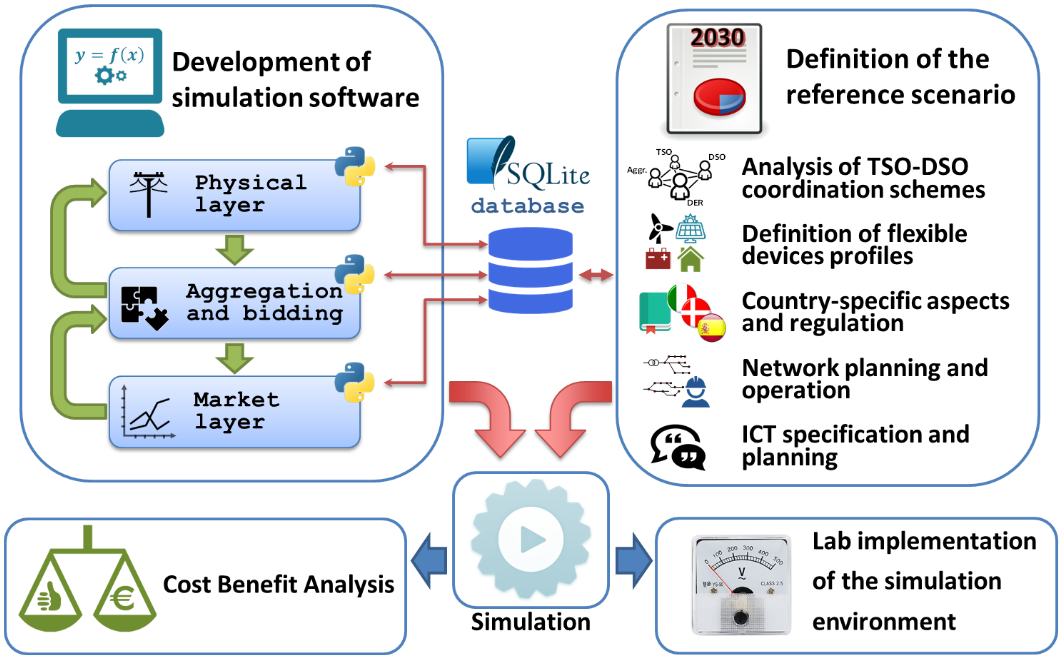
EC (2016) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity

Winter package assigns a role to DSOs for local congestion management, but not for balancing

The SmartNet project http://SmartNet-Project.eu SmartNet

Project video: https://vimeo.com/220969294/73d98edde6

- **architectures for optimized interaction between TSOs and DSOs** in managing the purchase of ancillary services from subjects located in distribution.
- **three national cases** (Italy, Denmark, Spain);
- *ad hoc* **simulation platform** (physical network, market and ICT)
- **CBA** to assess which TSO-DSO coordination scheme is optimal for the three countries.
- use of **full replica lab** to test performance of real controller devices.
- **three physical pilots** to demonstrate capability to monitor and control distribution by TSO and flexibility services that can be offered by distribution (thermal inertia of indoor swimming pools, distributed storage of radio-base stations).



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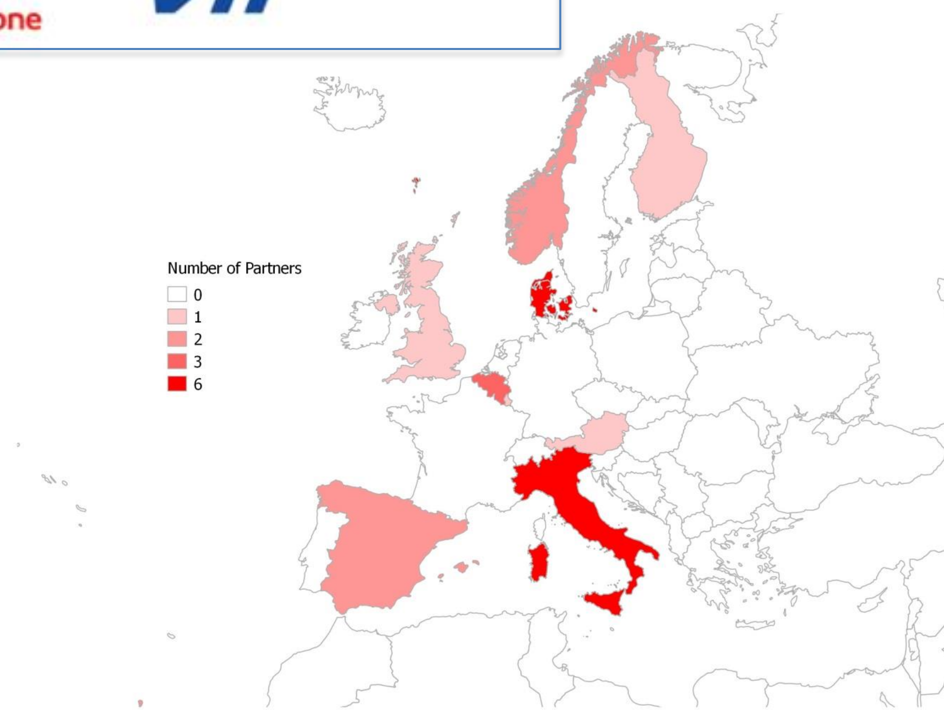
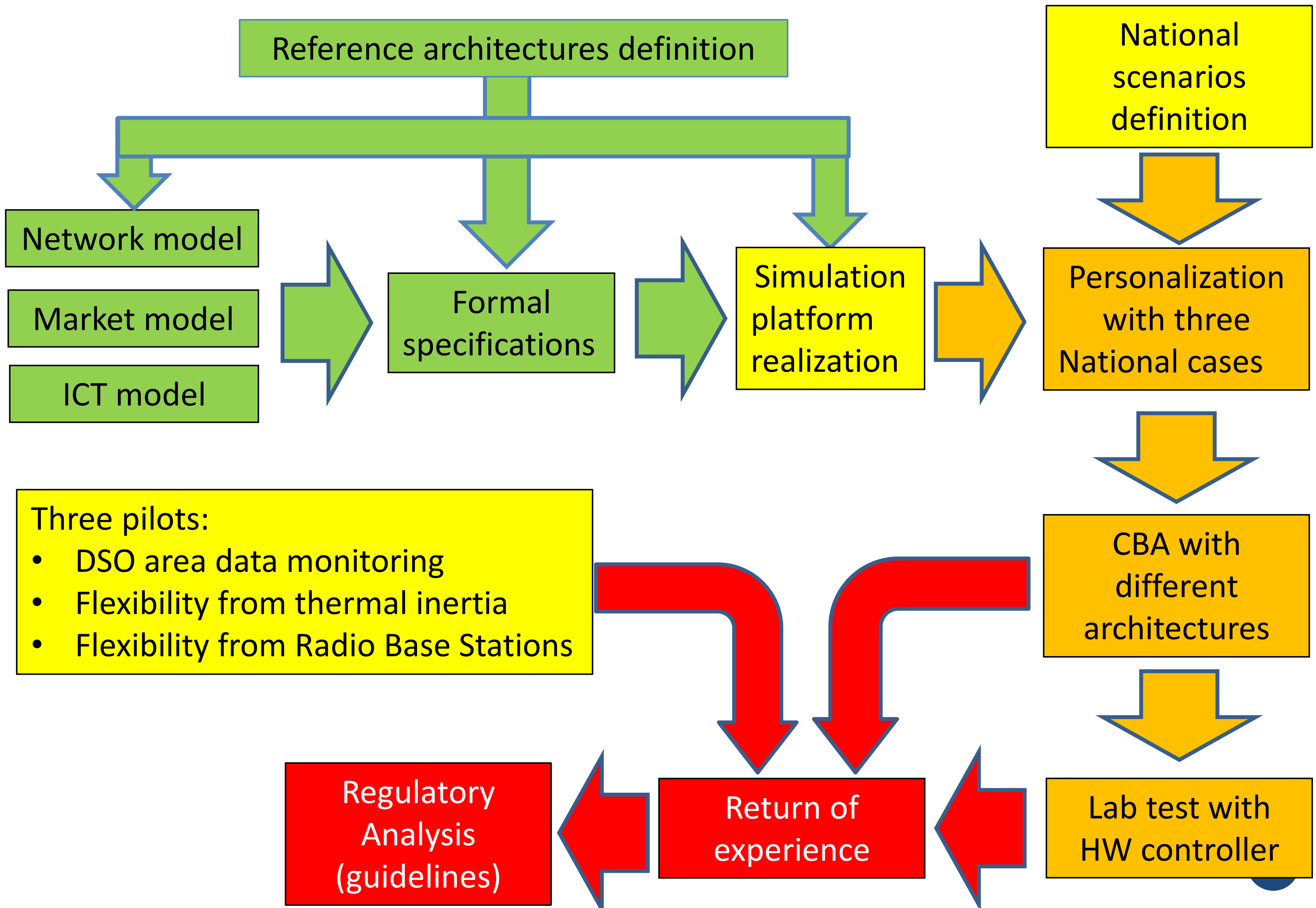


Year 1 – Year 2 – Year 3

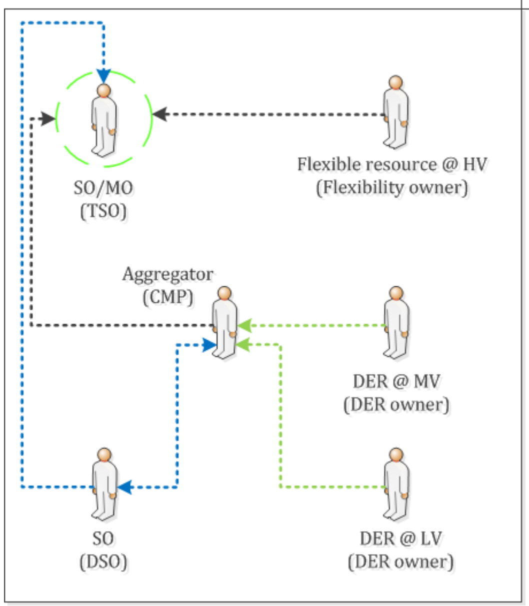


TSO-DSO coordination schemes

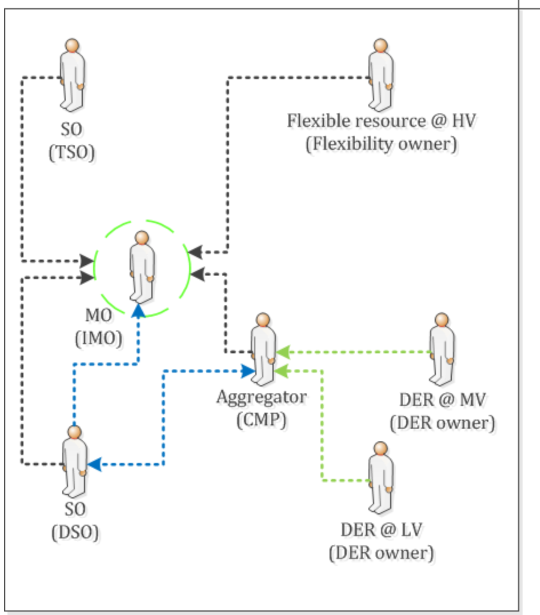
5 possible coordination schemes TSOs & DSOs for AS by distributed flexibility resources

A. Centralized AS market model
B. Local AS market model
C. Shared balancing responsibility model
D. Common TSO-DSO AS market model
E. Integrated flexibility market model

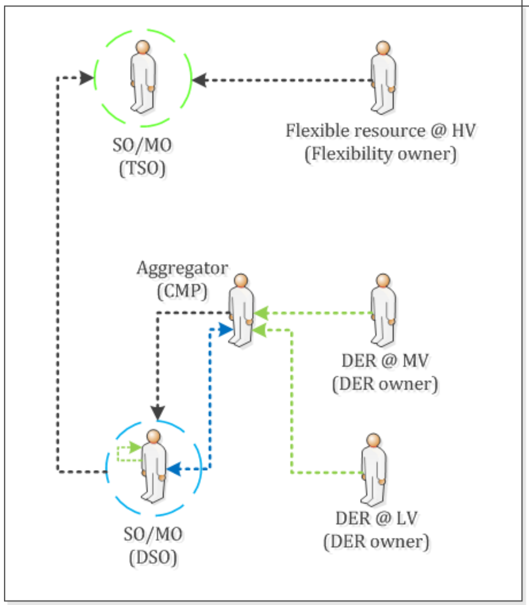
Centralized AS market model



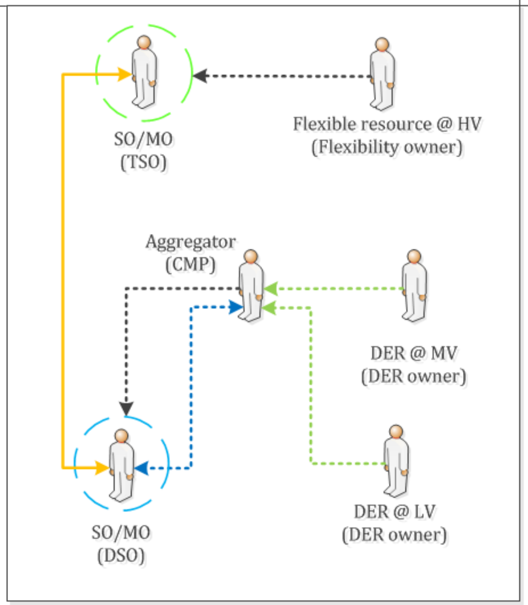
Integrated flexibility market model



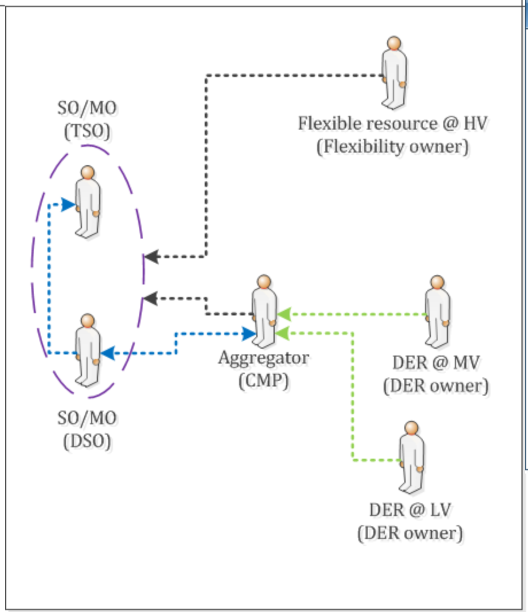
Local AS market model

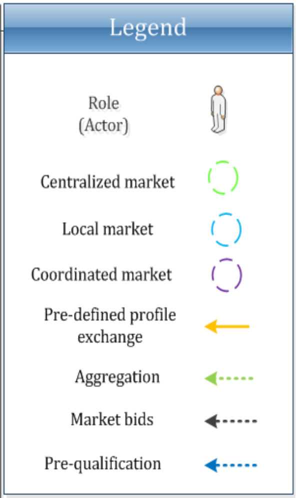


Shared balancing responsibility model



Common TSO-DSO AS market model





TSO-DSO coordination schemes: a comparison

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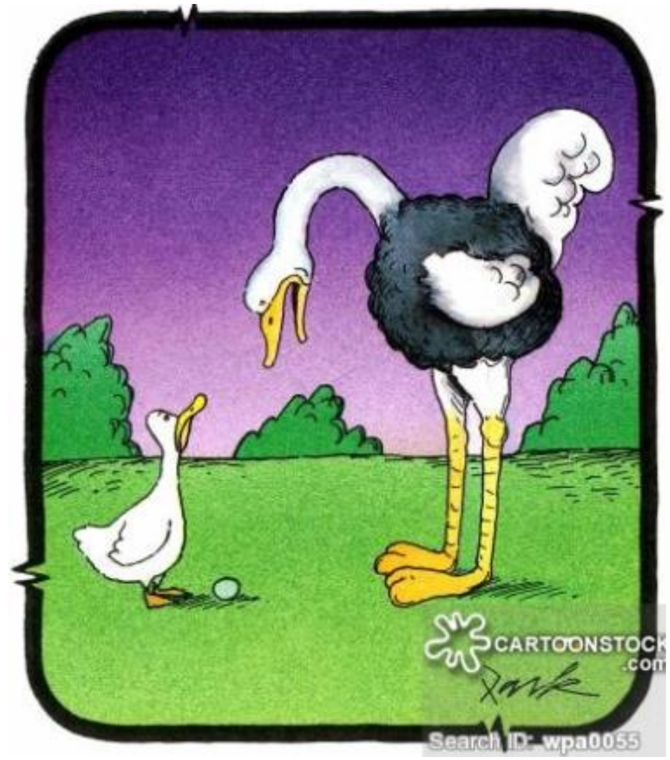
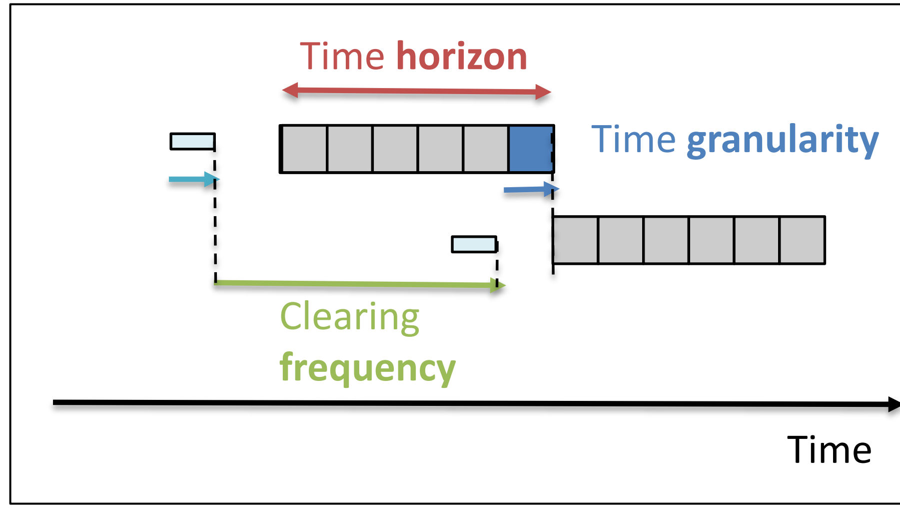
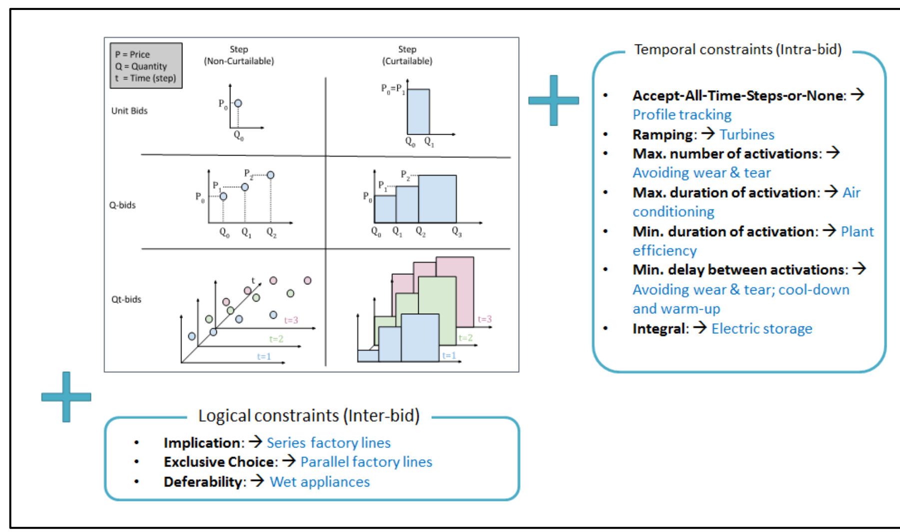
Coordination Scheme	Benefits	Attention points
Centralized AS market model	▪ Efficient scheme in case only the TSO is a buyer for the service ▪ A single market is low in operational costs and supports standardized processes ▪ Most in line with current regulatory framework	▪ No real involvement of DSO ▪ DSO grid constraints not always respected
Local AS market model	▪ DSO has priority to use local flexibility ▪ DSO supports actively AS procurement ▪ Local markets might create lower entry barriers for small scaled DER	▪ TSO and DSO market cleared sequentially ▪ Local markets might be rather illiquid ▪ Need for extensive communication between the TSO market and the local DSO markets
Shared balancing responsibility model	▪ The TSO will need to procure a lower amount of AS ▪ Local markets might create lower entry barriers for small scaled DER ▪ Clear boundaries between system operation TSO and DSO	▪ Total amount of AS to be procured by TSO and DSO will be higher in this scheme ▪ BRPs might face higher costs for balancing ▪ Small local markets might be not liquid enough to provide sufficient resources for the DSO ▪ Defining a pre-defined schedule methodology agreed by both TSO/DSO might be challenging
Common TSO-DSO AS market model	▪ Total system costs of AS for the TSO and local services for the DSO are minimized ▪ TSO and DSO collaborate closely, making optimal use of the available flexible resources	▪ Individual cost of TSO and DSO might be higher compared to other schemes ▪ Allocation of costs between TSO and DSO could be difficult
Integrated flexibility market model	▪ Increased possibilities for BRPs to solve imbalances in their portfolio ▪ High liquidity and competitive prices due to large number of buyers and sellers	▪ Independent market operator needed to operate the market platform ▪ Negative impact on the development and liquidity of intraday markets ▪ TSO and DSO need to share data with IMO



Proposed Market Design

- **Considered services: balancing** and **congestion** management at transmission (HV) and distribution level (MV), including voltage constraint at MV
- **Rolling optimisation concept:** Results for the **first** time step are a **firm** decision. Results for the **next** time steps are **advisory** decisions.
- **Network representation:** DC approximation for HV, SOCP for MV
- **Market products:** implementation of typical constraints of flexibility providers (extension to **multi-period bids** with **temporal** and **logical** constraints
- **Representation of arbitrage opportunity between cascading markets:** day-ahead, intraday, AS market





The SmartNet simulation platform

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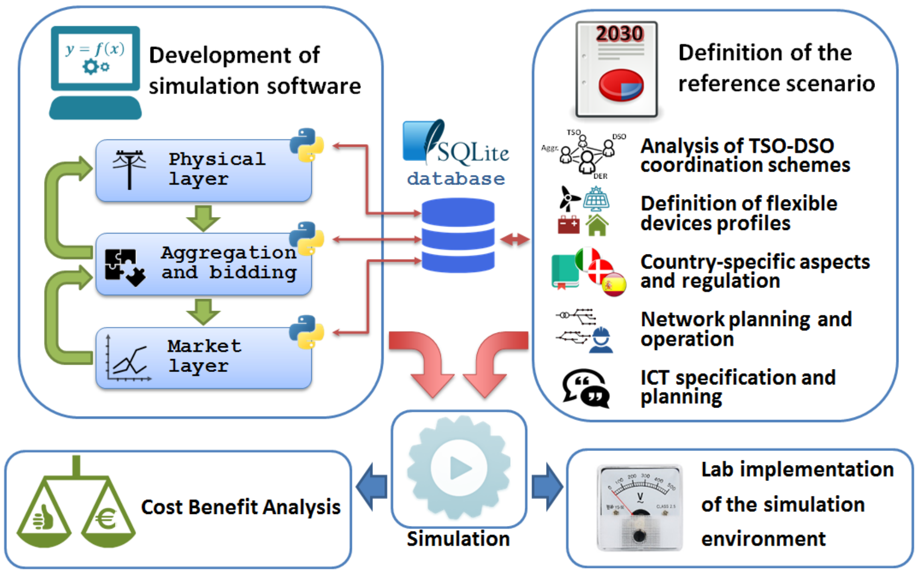
The physical layer simulates T&D and devices operation, including voltage regulation, reactive compensation, aFRR and network protections.

The bidding layer aggregates flexibility offers of a huge number of resources (electric storage, electric vehicles, distributed generation, demand response) into balancing market bids and transforms market clearing into activations.

The market layer carries out system balancing and congestion management while including voltage constraints.
Some innovative features are:

- **rolling optimisation** concept
- **network representation:** DC approximation for HV networks, SOCP for MV networks
- **market products:** typical **multi-period** and **logical** constraints of flexibility providers
- **arbitrage opportunities between cascading markets (**day-ahead, intraday, AS market).

Simulation scenarios at 2030 for Italy, Denmark and Spain. Very large datasets (Italian scenario: 655,323 photovoltaic panels, 31 wind farms, 20 large CHP plants, 1,833 run-of-river hydropower plants, 308 conventional fuel-based generators, 13 pumped hydro stations, 212,704 electrical cars, 1,489,193 residential wet appliances, 68,481 residential heat pumps, 33,783 dimmable street-lights, as well as non-controllable loads in all distribution grids and some transmission nodes.



Cost benefit analysis compares the 5 coordination schemes over 3 national scenarios on the basis of:

- **total AS market cost**
- **aFRR cost** due to congestion not "seen" by AS market, forecasting errors, transmission losses (neglected by AS market).
- **unwanted measures**
- **ICT deployment costs**

Sensitivity factors:

- **emission savings**

Further "micro" **cash flows analysis**.

Hardware-in-the-loop simulations to test in real-time-simulated scenarios the performances of real equipment (controllers for flexible devices, SCADAs, etc.) and the effects of non-ideal information transmission channels.

Interaction between the three layers

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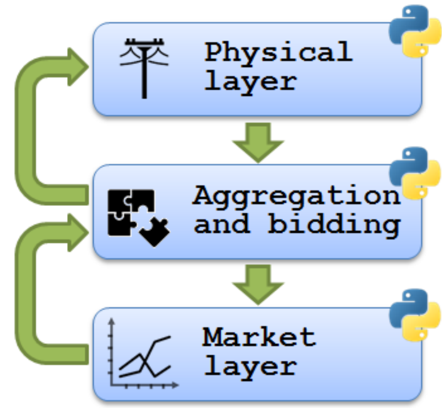
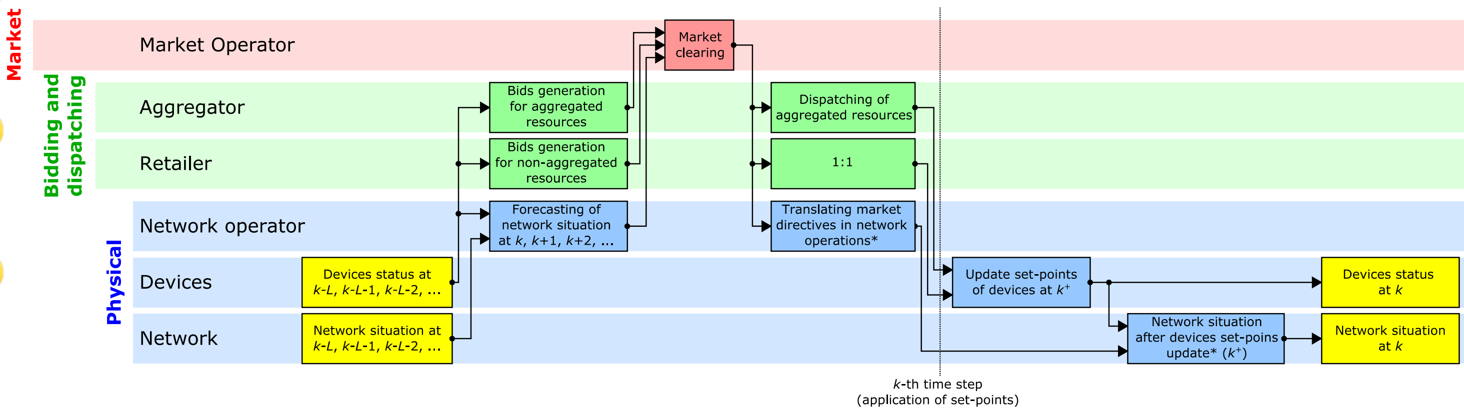
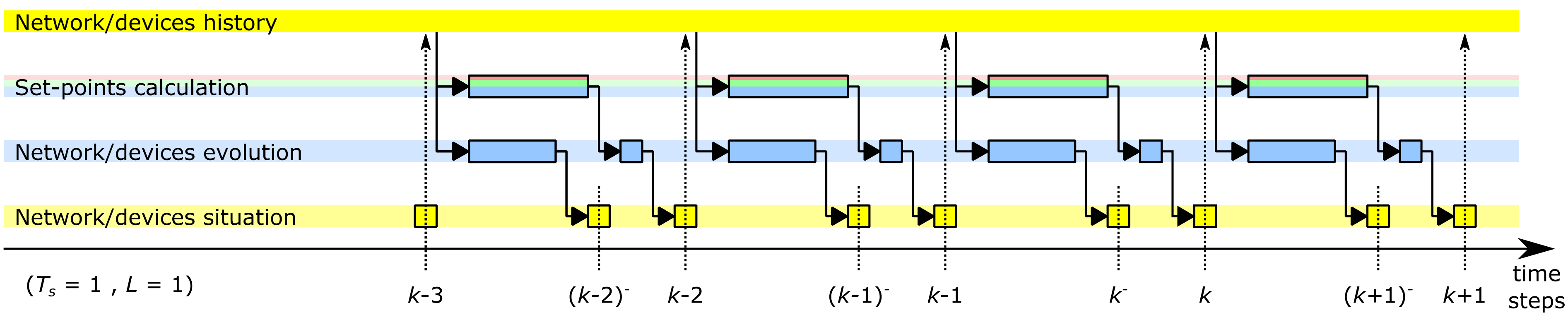
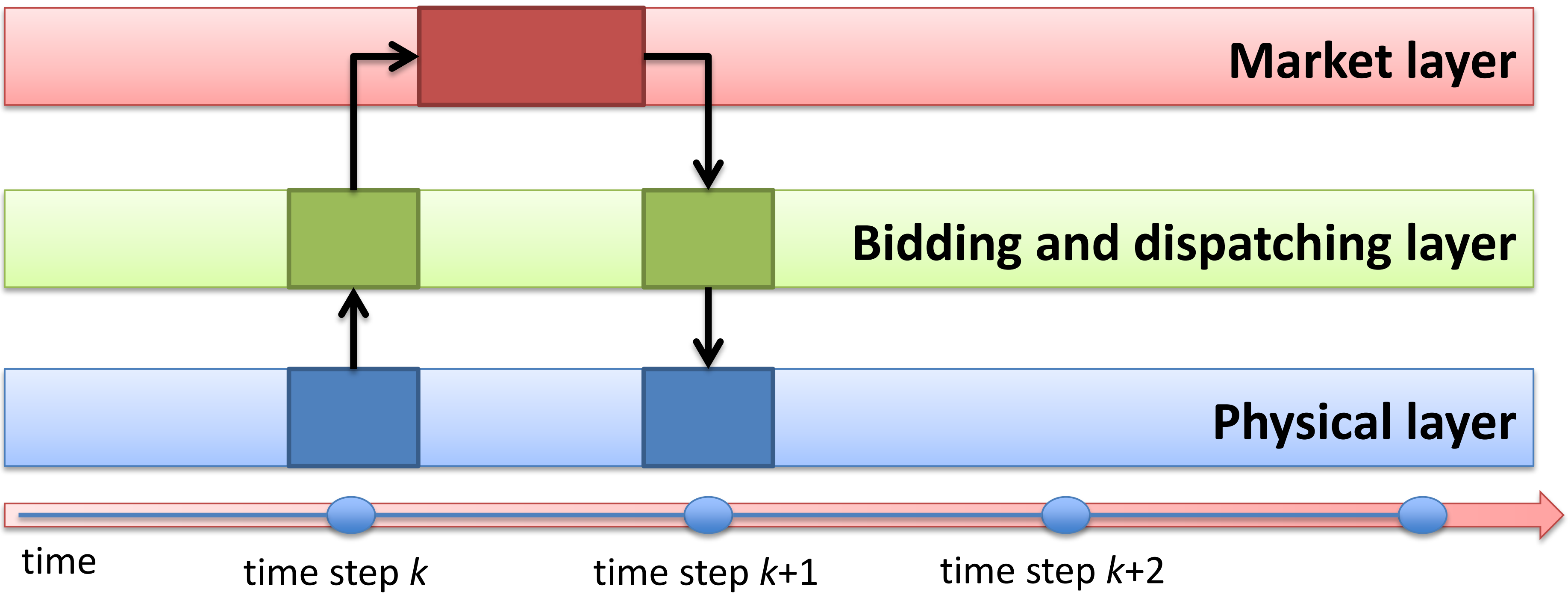


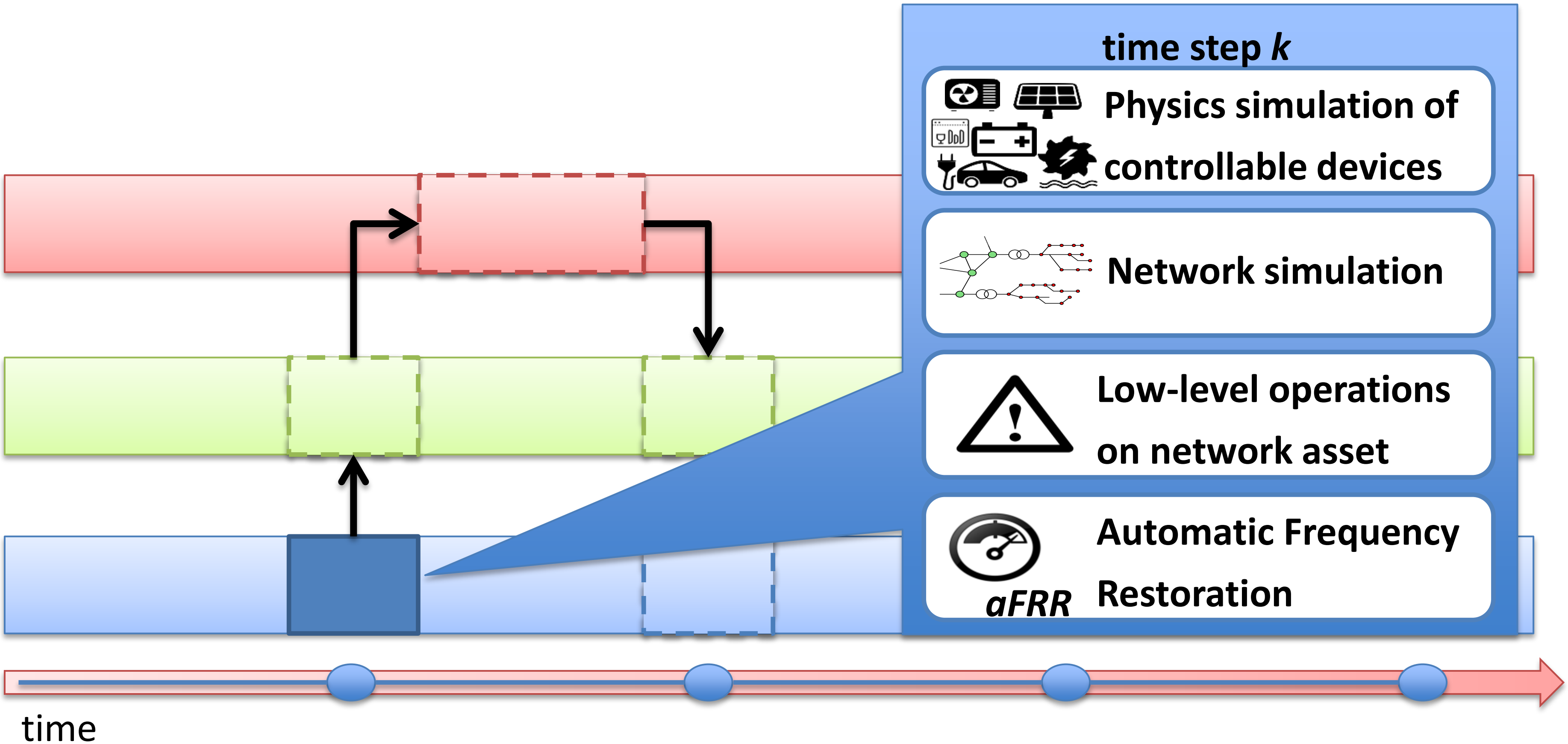




How the simulator works
Simulation based on three layers

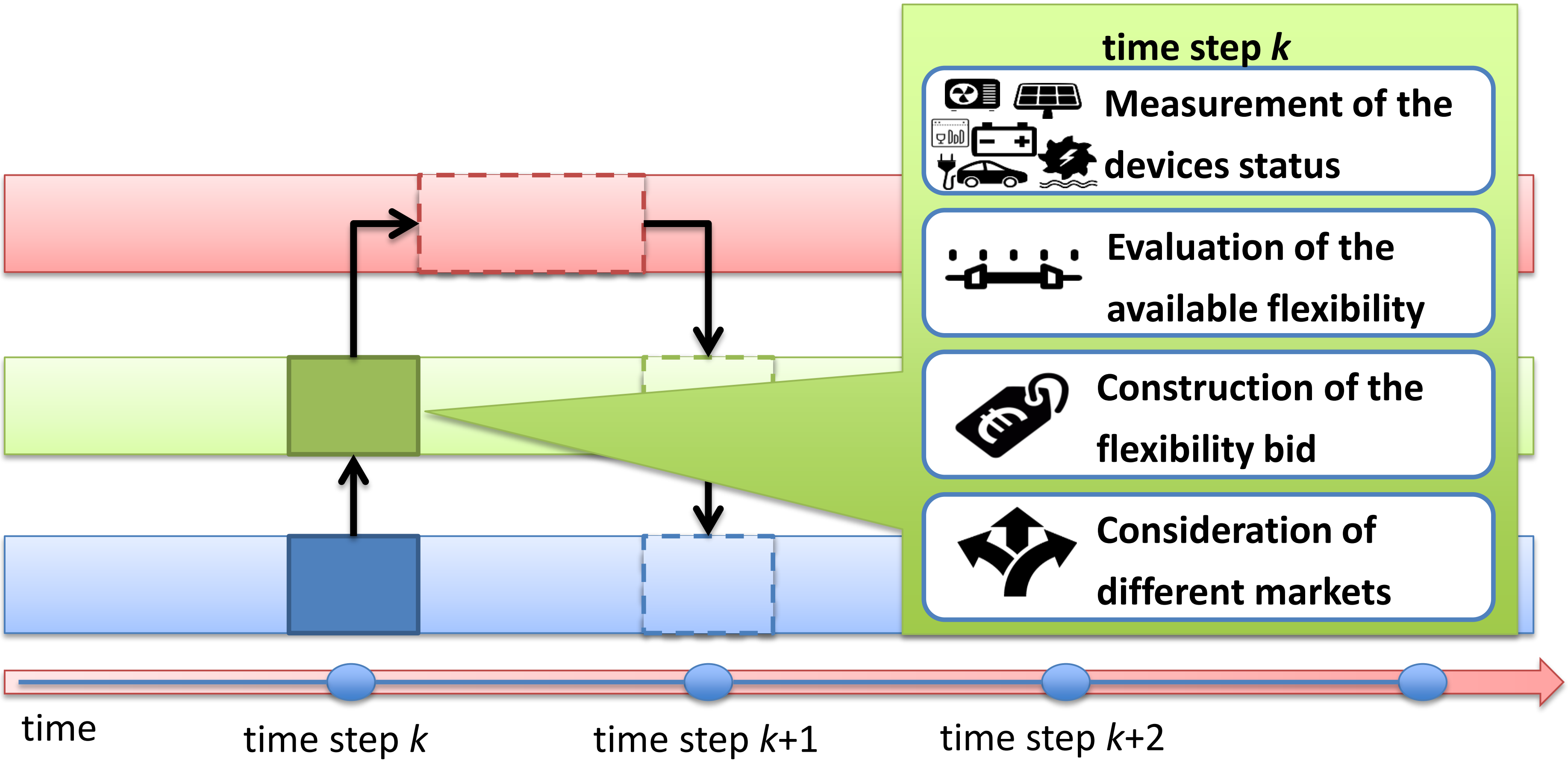


How the simulator works



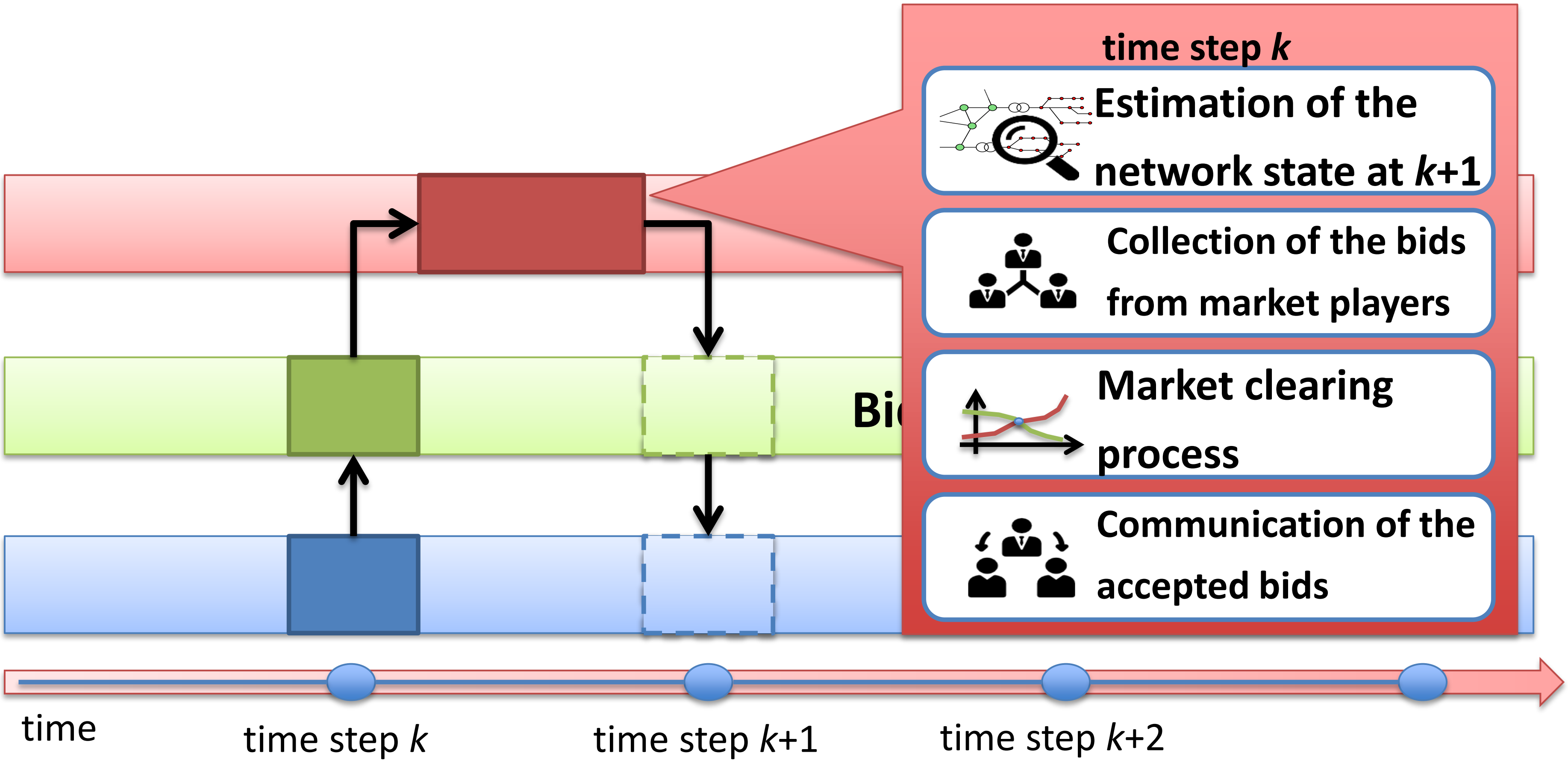
How the simulator works

How the bidding process is simulated



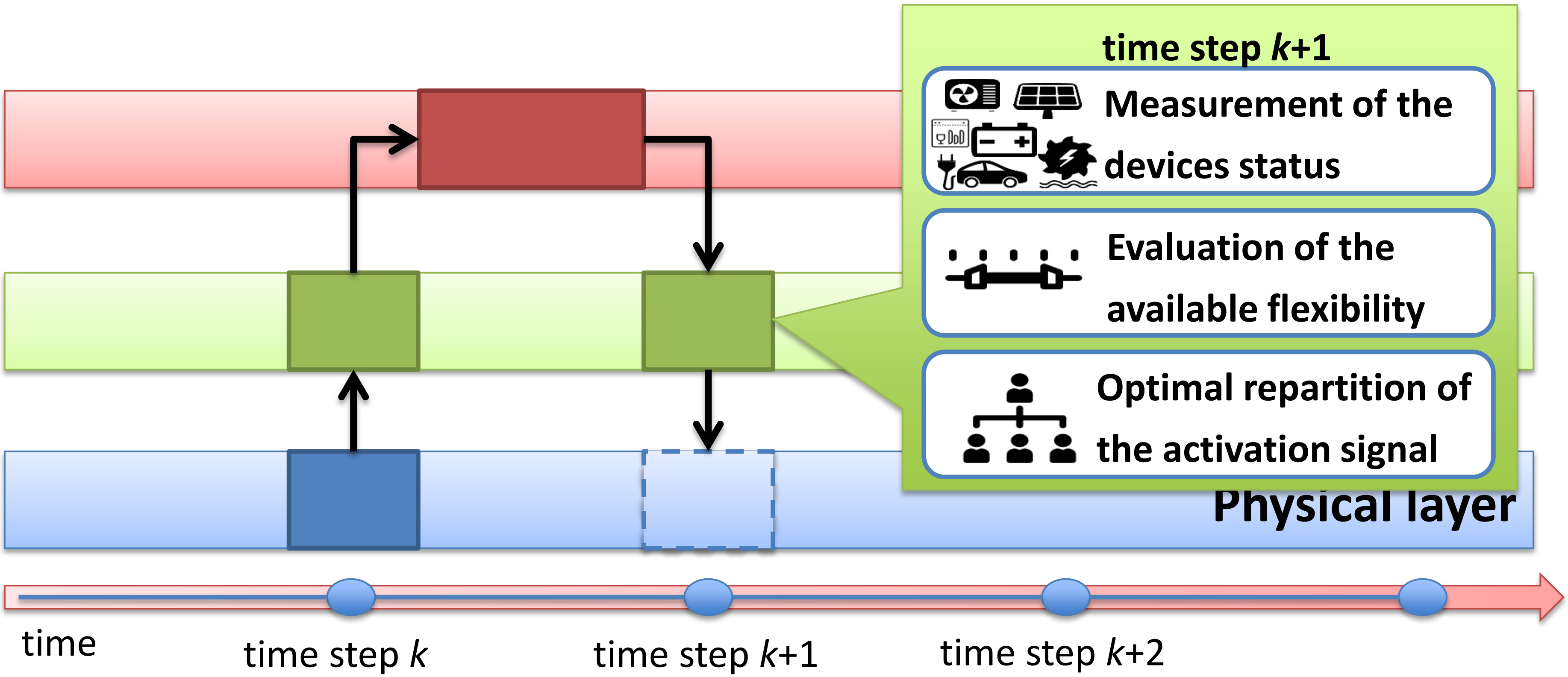
How the simulator works

How the market process is simulated

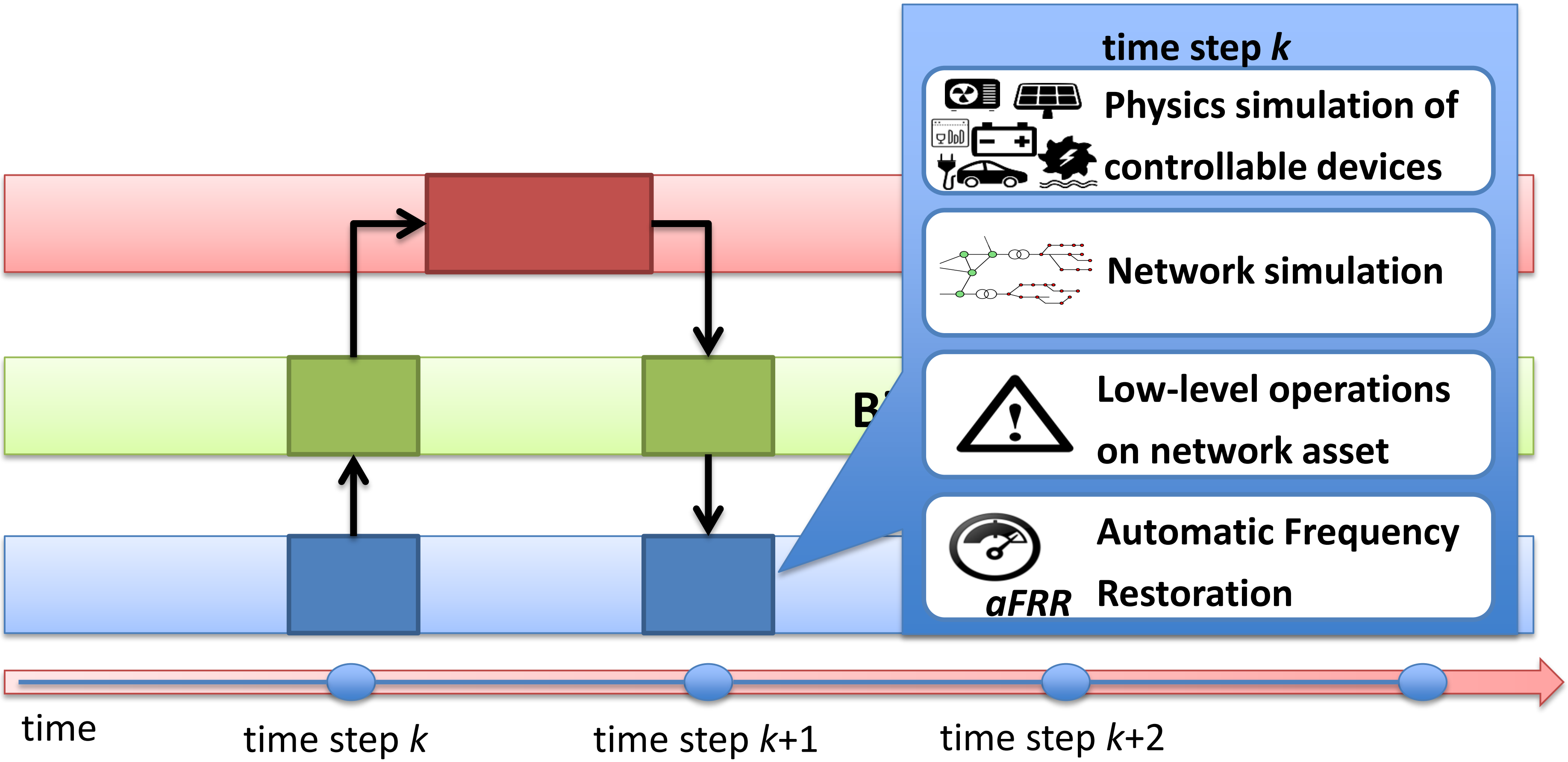


How the simulator works

How the dispatching process is simulated



How the simulator works
How the physical layer is simulated



Balancing market and aFRR (1/2)

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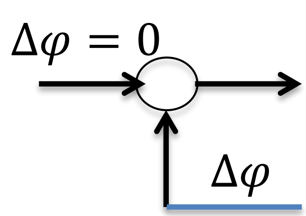
Tertiary market mFRR
(balancing + congestion management)

Residual congestion and imbalance
congestion not detected by tertiary market and imbalance/congestion due to forecasting errors

Unwanted measures
(re-dispatching to remove residual congestion) creating further imbalance

Residual imbalance

aFRR in physical layer
(system balancing: by controlling flows with neighbouring countries)



CBA

Cost mFRR
Energy awarded but not delivered (forecasting errors) is paid only for actual delivery (= imbalance settlement at tertiary market price) New

Cost Unwanted Measures

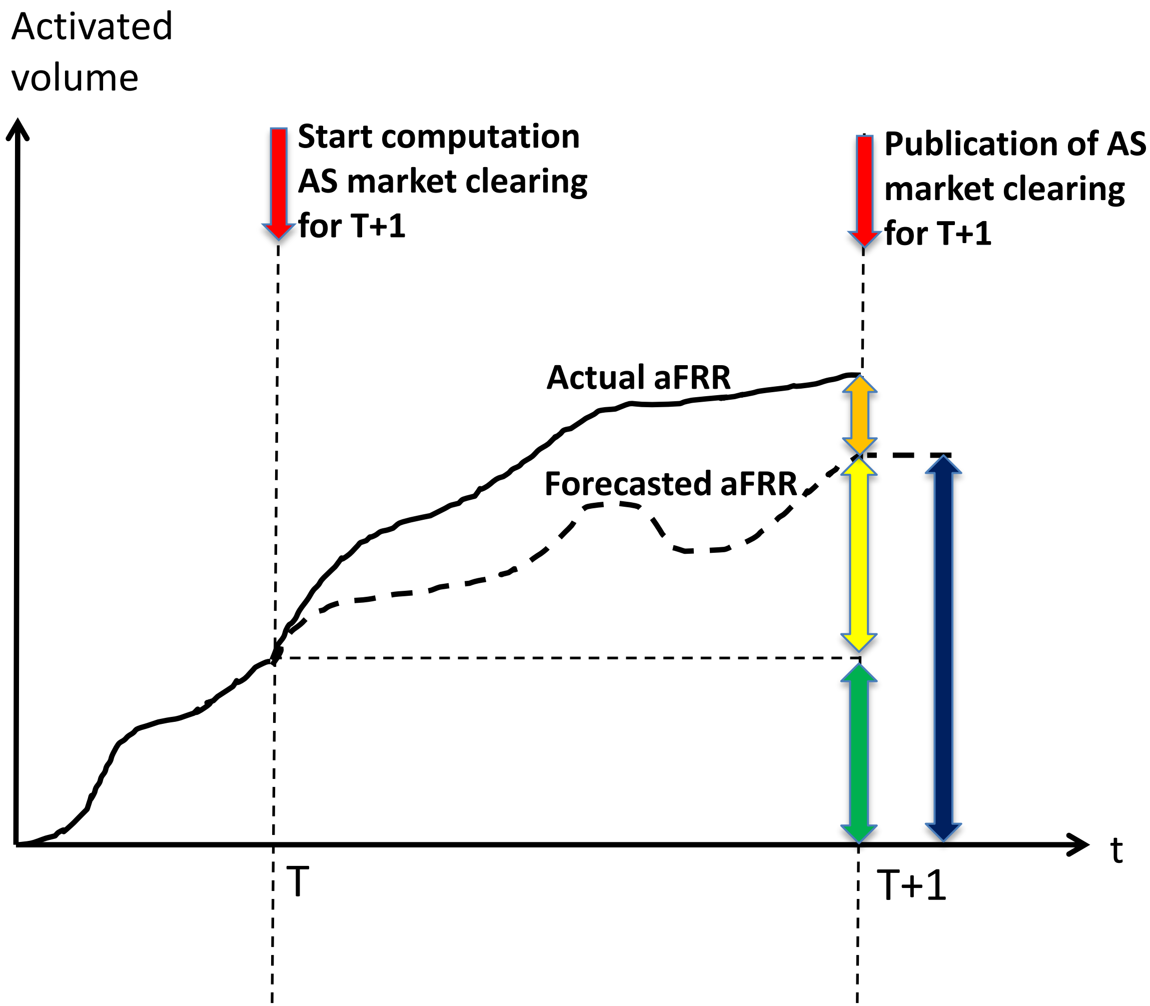
Paid at tertiary market bid price New

Cost aFRR, higher than mFRR:

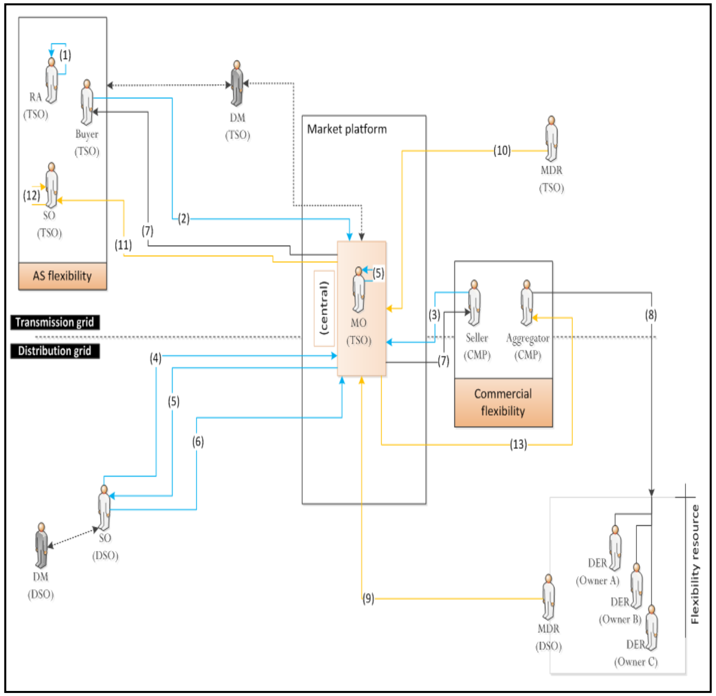
$P_{mFRR\_BID}*k$
$k < 1$ if $P_{mFRR\_BID} < 0$
$k > 1$ if $P_{mFRR\_BID} > 0$

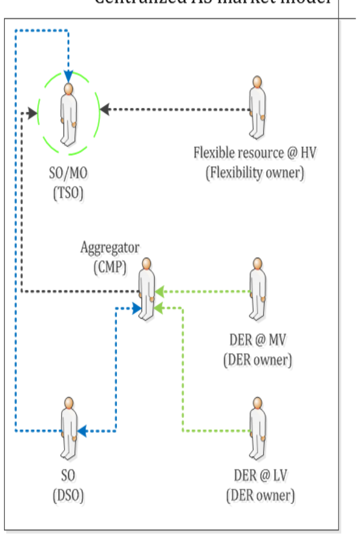
Balancing market and aFRR (2/2)

- aFRR volume already activated before T and not yet released (green)
- Forecasted further aFRR volume activated to compensated imbalance between T and T+1 (yellow)
- Actual aFRR volume activated between T and T+1 (different from forecast due to forecast errors and CS imperfections in representing the system (orange)
- Volume of tertiary reserve activated by the AS market at T+1 (dark blue)



Analysis of information flows for each CS





Centralized AS market model

	Steps (#)	Origin	Action	Recipient
Procurement	1	RA (TSO)	Determines volumes to be procured	
	2	Buyer (TSO)	Communicates volumes to	MO (TSO)
	3	Seller (CMP)	Sends aggregated bids (from transmission and distribution) to	MO (TSO)
	4	SO (DSO) (*)	Communicates distribution grid constraints to	MO (TSO)
	5	MO (TSO)	Clears market and communicates results to	SO (DSO)
	6	SO (DSO) (**)	Checks if local constraints allow for activation requested by TSO and blocks if needed – communication to MO and step 5 will be repeated	MO (TSO)
Activation	7	MO/FD (TSO)	Communicates results to (activation is simultaneous if no capacity is procured)	Buyer (TSO) Seller (CMP)
	8	Aggregator/FD (CMP)	Activates units based on the selected bids	DER
Settlement	9	MDR (DSO)	Communicates measurements to	MO (TSO)
	10	MDR (TSO)	Communicates measurements to	MO (TSO)
	11	MO (TSO)	Communicates measurements to	SO (TSO)
	12	SO (TSO)	Corrects perimeter of BRPs affected by activation	
	13	MO (TSO)	Performs financial settlement of flexibility activation for resources connected at distribution and transmission grid	Aggregator (CMP)

ICT requirements: a SGAM analysis framework

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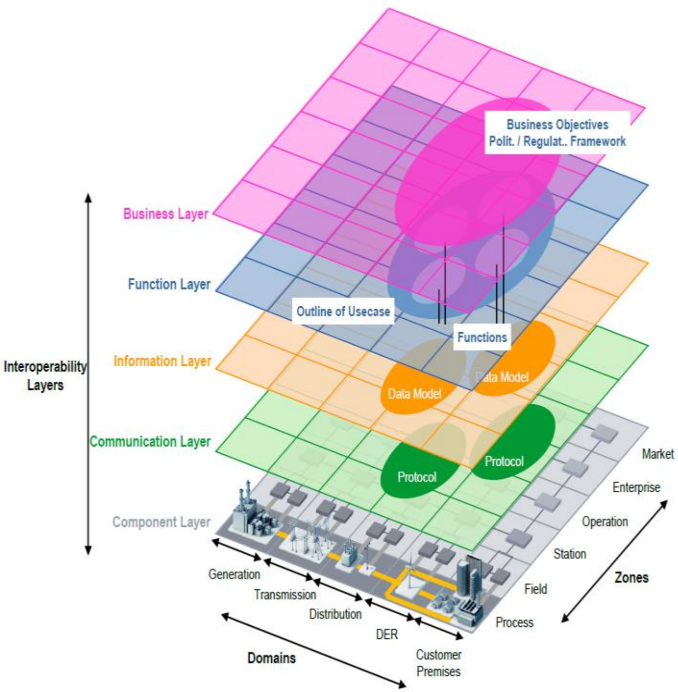
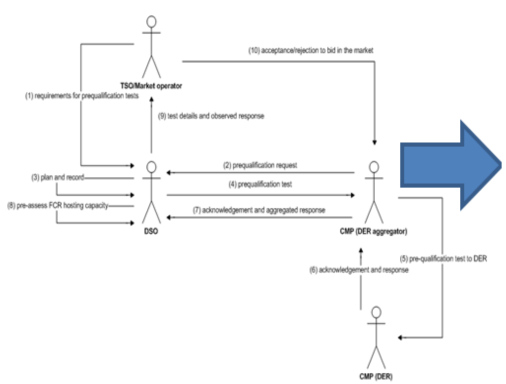
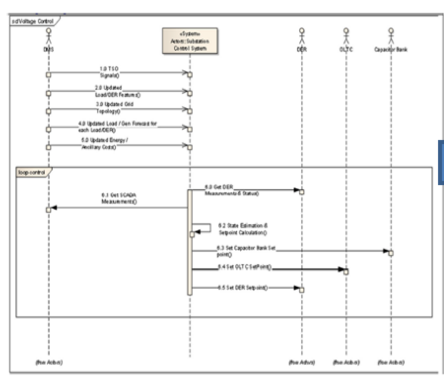


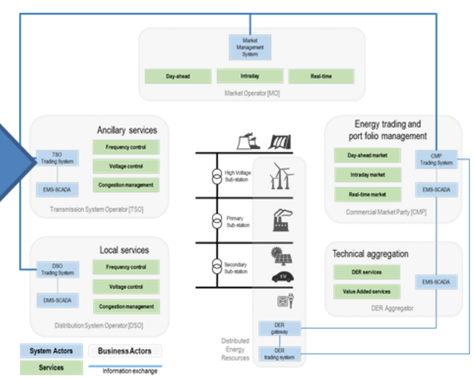
- **Use Case Analysis:** to create an initial use case description.
- **Business Layer Design**: business processes, services, and organizations linked to the use case
- **Function Layer Design:** functions, derived from the initial use case description.
- **Component Layer Design:** components needed for use cases, assigned to domain and zone. Subsequently, to a corresponding hardware.
- **Information Layer Design:** information exchanged between functions, services, and components identified, by analysing the data exchanged between actors
- **Communication Layer Design:** suitable communication protocols and ICT techniques



Business and function layers



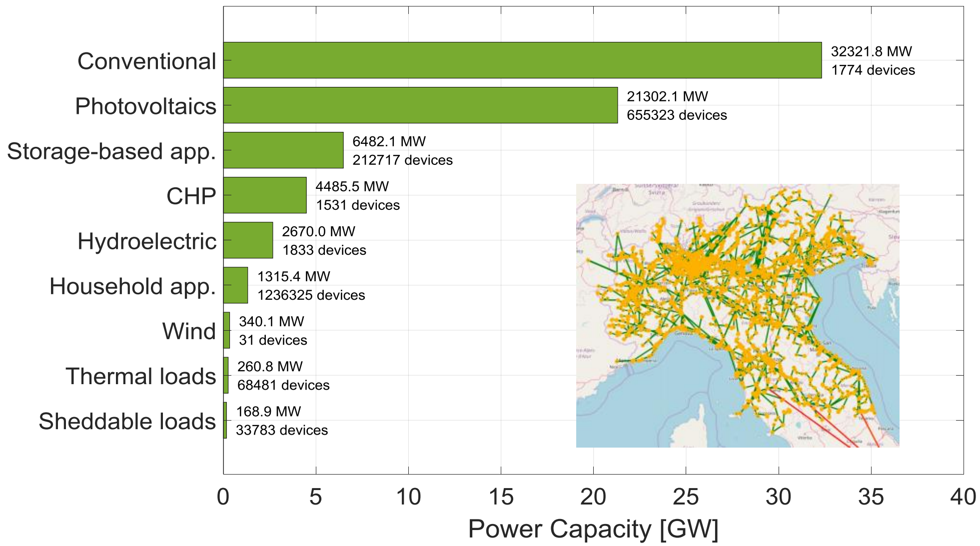
Information layer

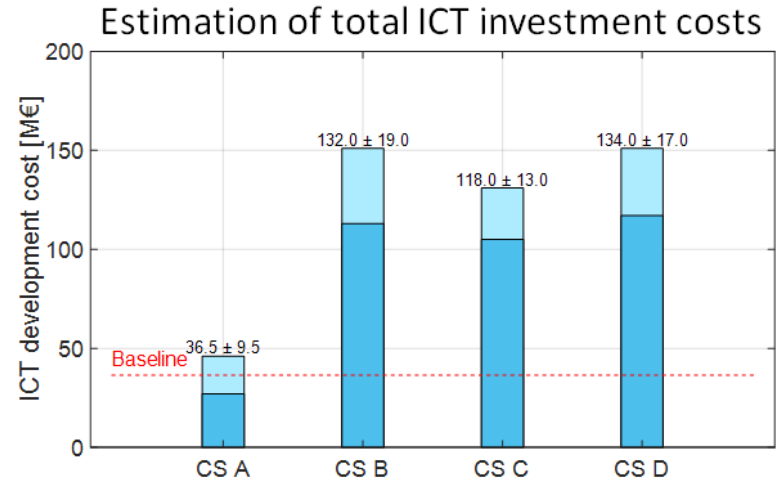


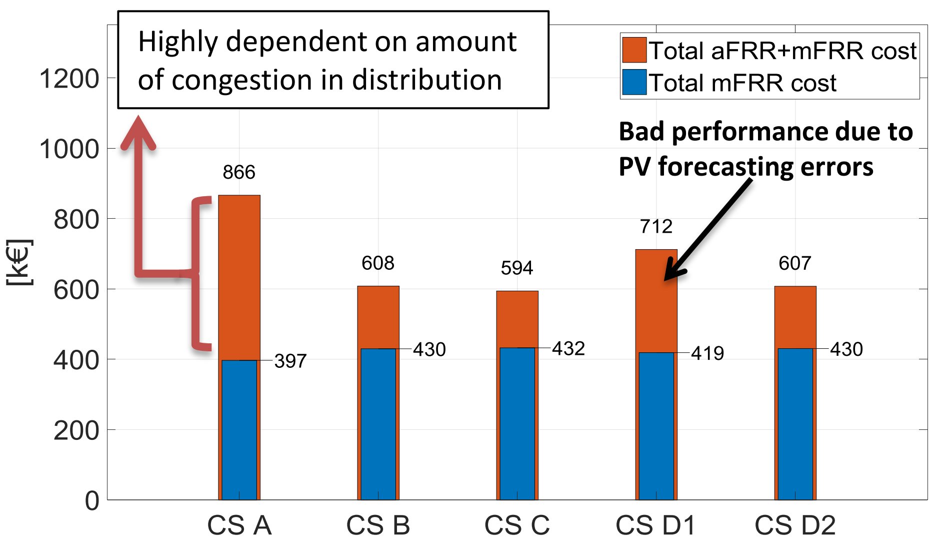
Communication and component layers

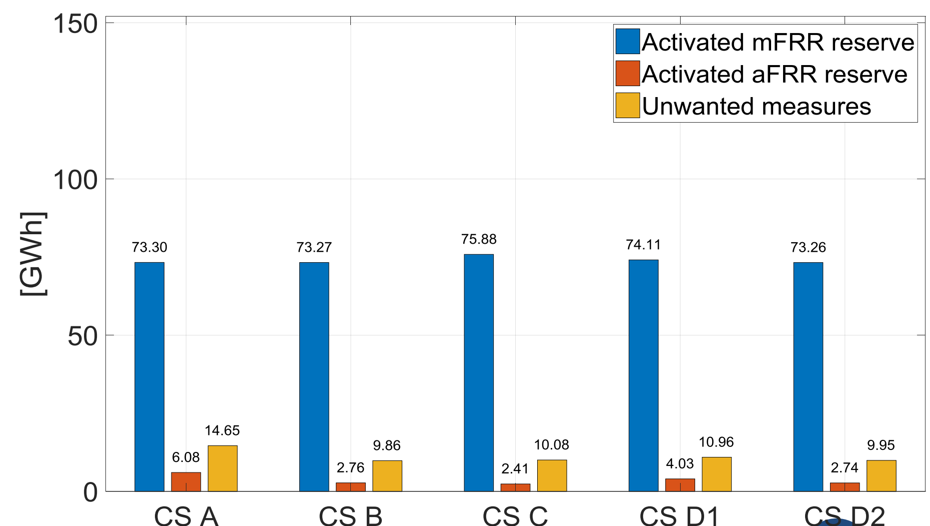
Results for the Italian simulation scenario

New features still not considered



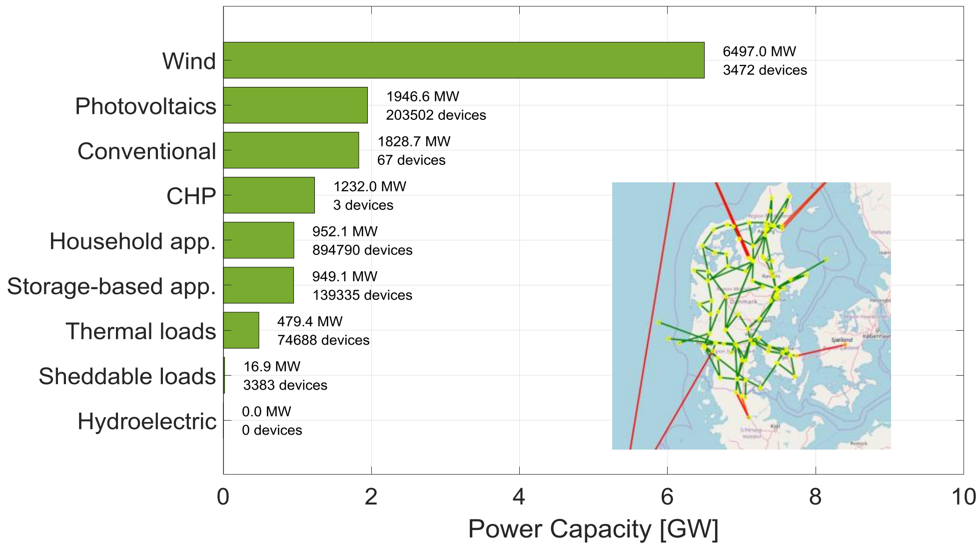


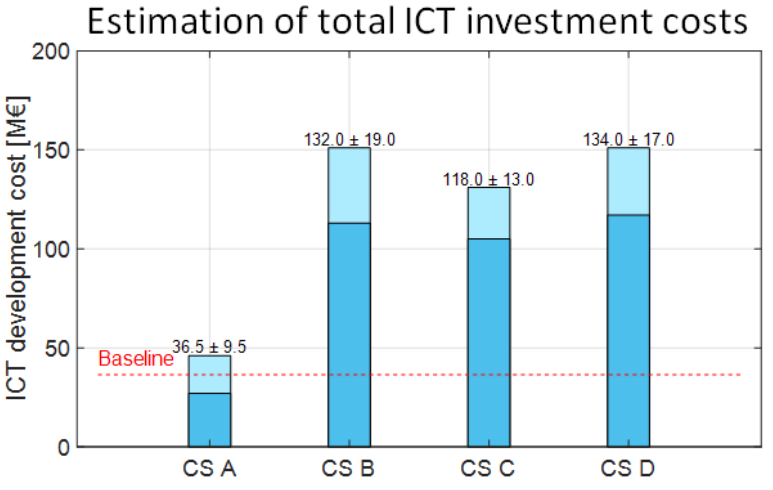


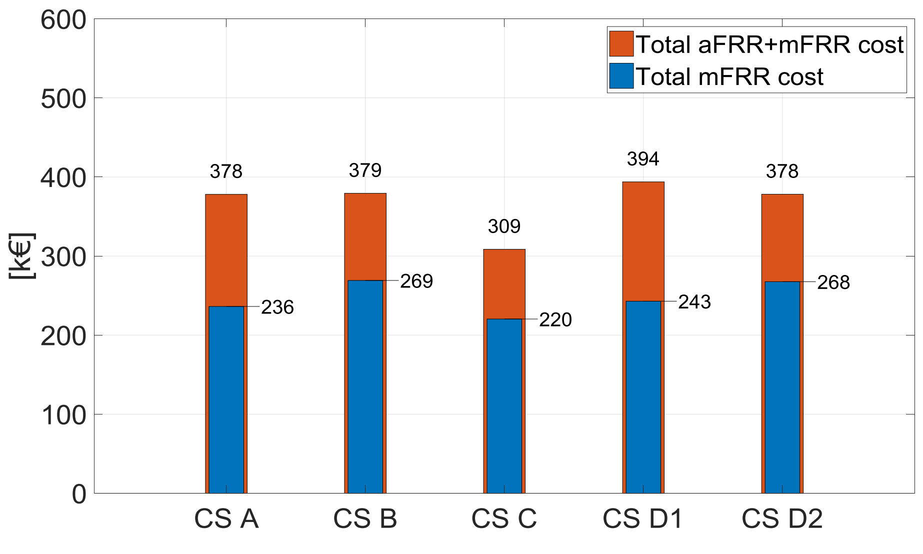


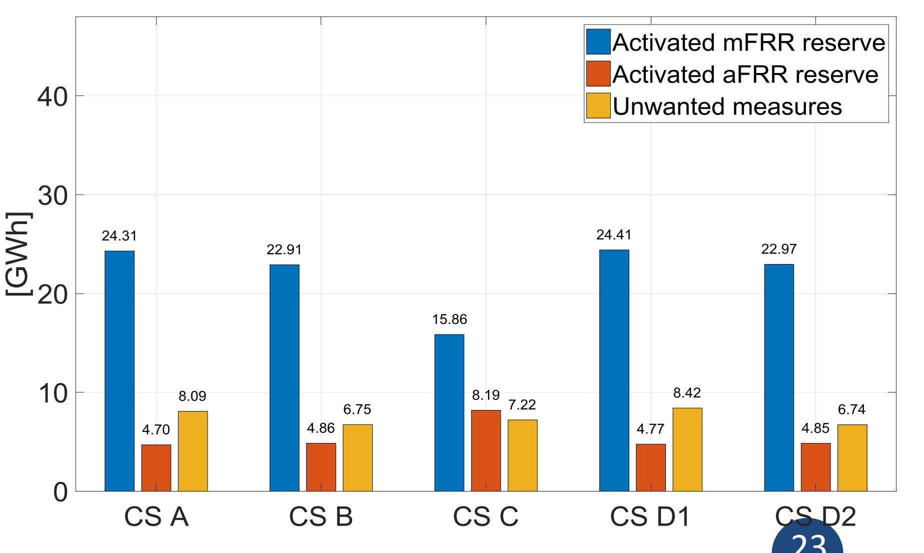
Results for the Danish simulation scenario

New features still not considered



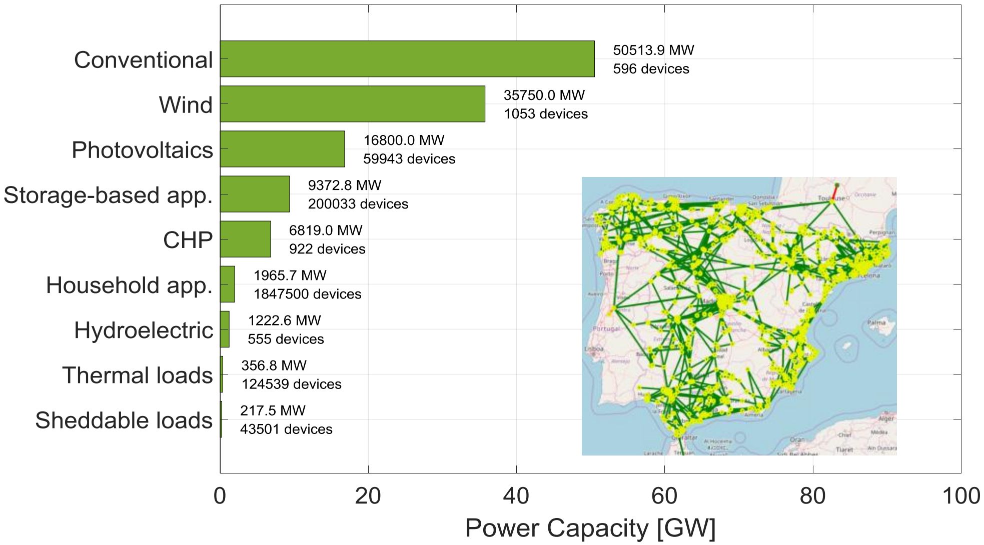


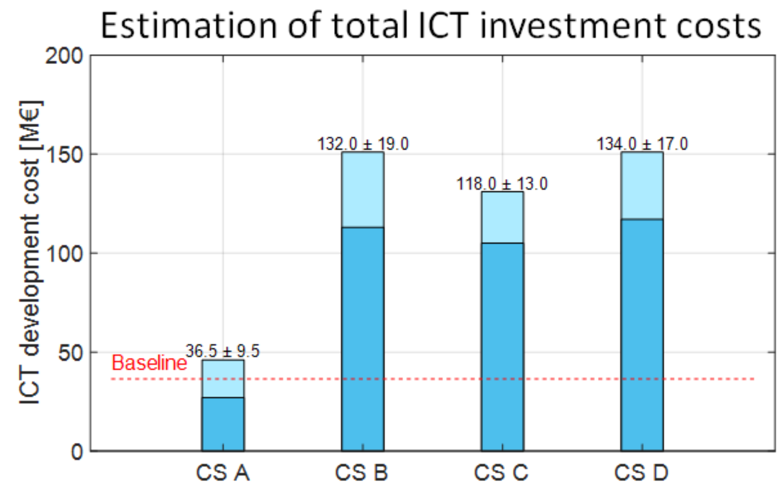


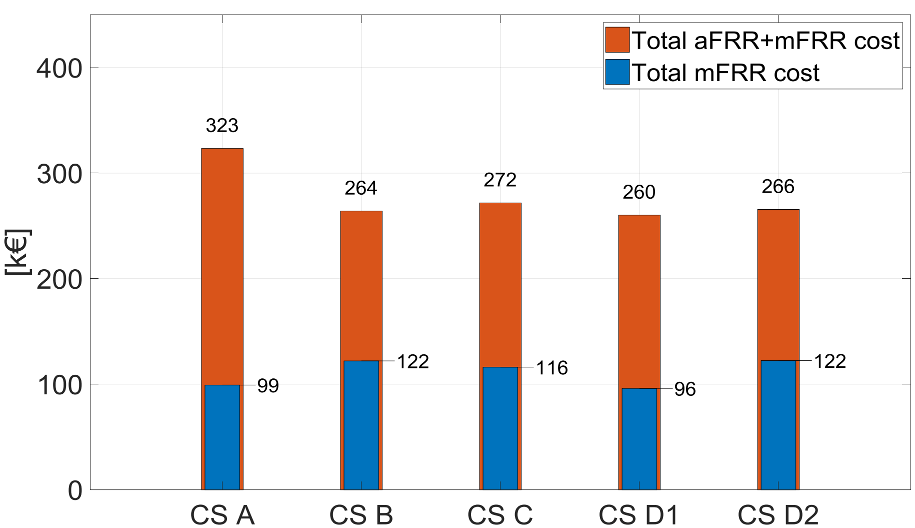


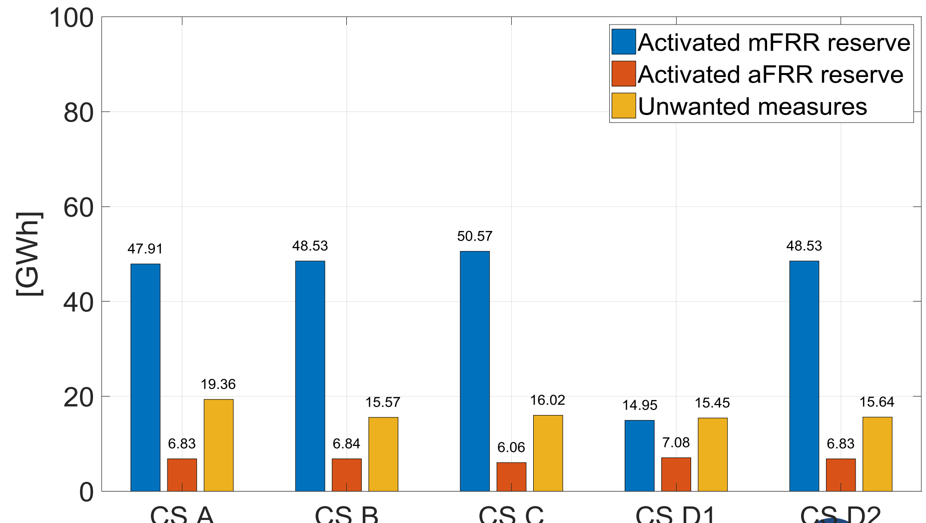
Results for the Spanish simulation scenario

New features still not considered







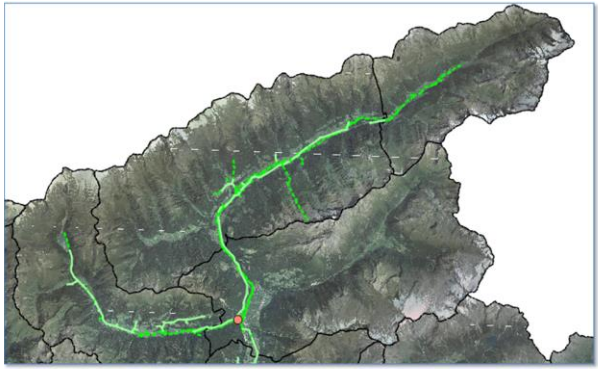


The Italian Pilot A

Observability (20s) at primary substation

Voltage regulation (4 s) with generators in HV and MV sections

Power-frequency regulation & balancing (4s) with MV generators

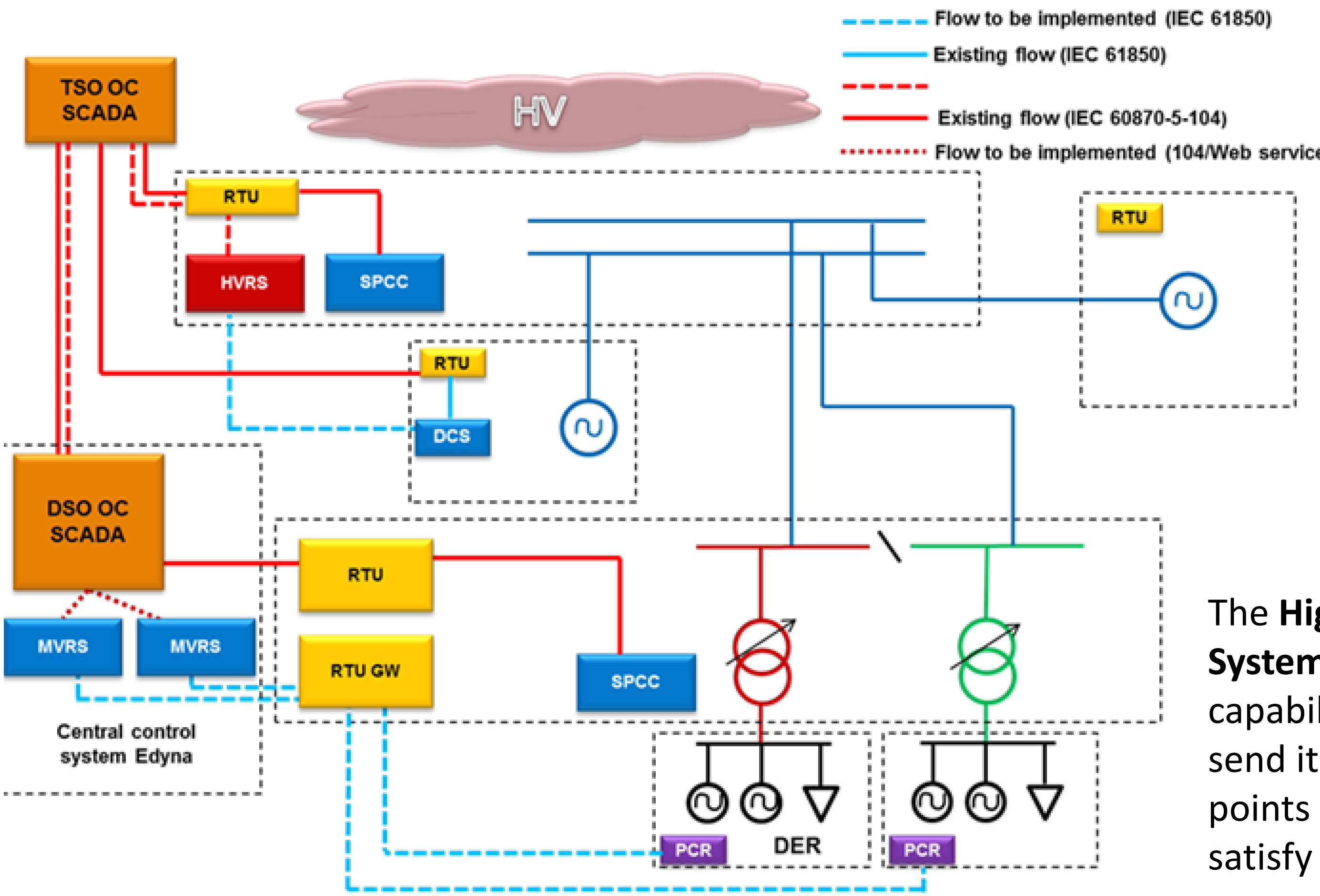


- The pilot is located in Ahrntal, characterized by
  - a long “antenna” distribution network with little load
  - many hydroelectric plants connected to different voltage levels
  - the significant number of installations at MV and LV grid leads often to reverse flow (summer peak > 30MW)

- **HV part of the pilot**: two hydroelectric plants Molini and Lappago (20MW each) both connected to the same HV substation (Molini di Tures)
- **MV part of the project**: the project involves the MV grid powered by the primary substation “Molini di Tures” of DSO; 23 connected producers, with an installed power of 29 MW (27.7 run-of-river hydro power, 1.5 biomass, 0.2 PV), and 5 local DSOs characterized by a small number of customers fed by one or more hydro power plants.

Pilot A: monitoring and control

It implements an «intelligent» version of CS_A by additionally estimating the virtual capability at the TSO/DSO interconnection point



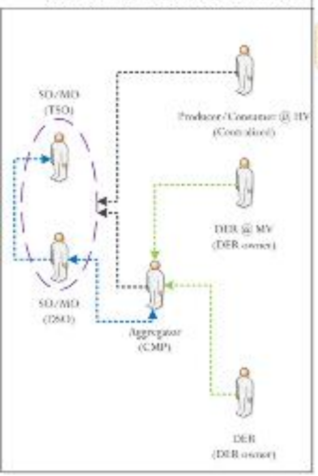
The **Plant Central Regulators (PCR)** represents the most peripheral device in the communication chain between the TSO and the plant. It makes available the functions of reactive power modulation and active power modulation.

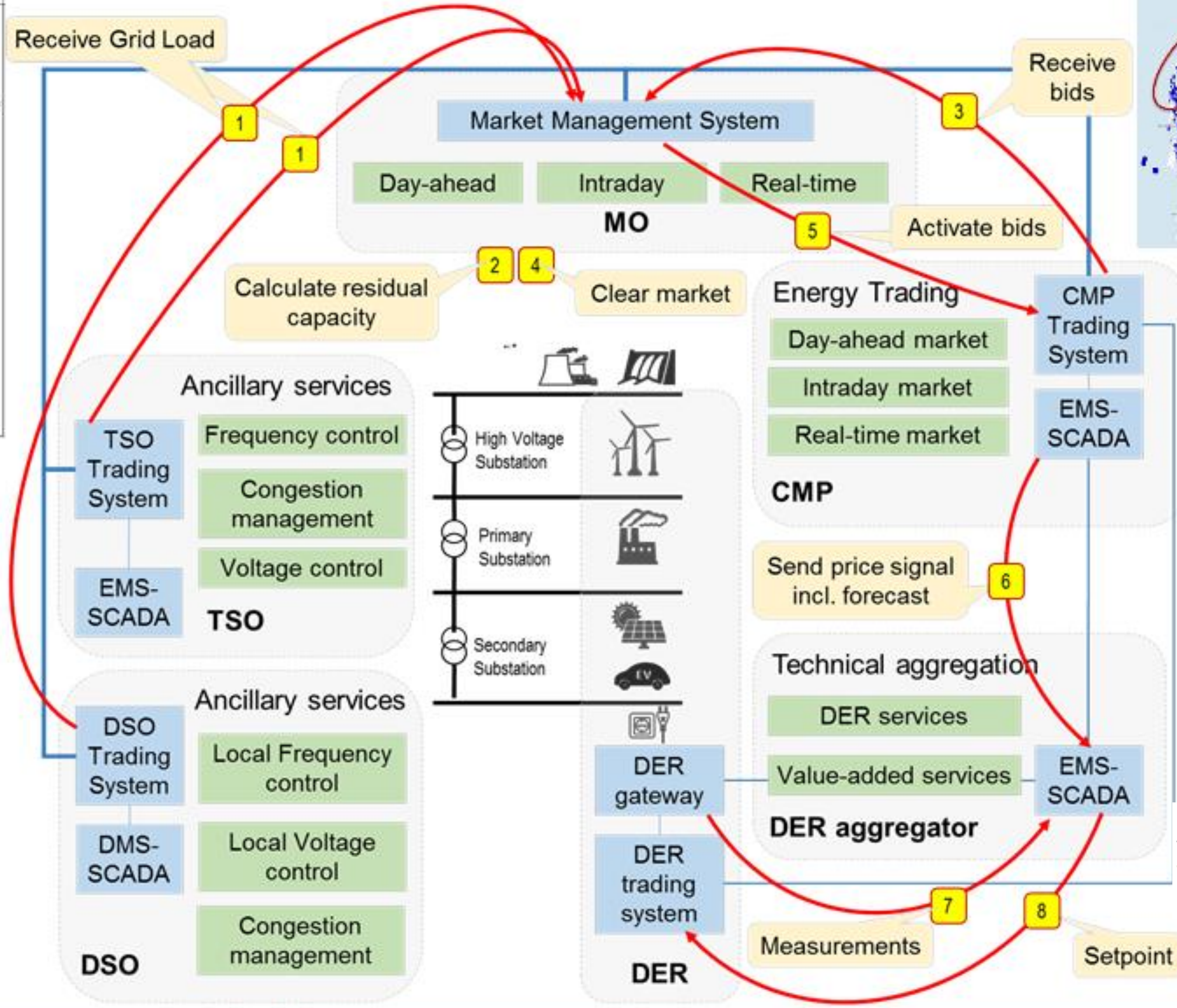
The **High Voltage Regulation System (HVRS)** calculates reactive capability of the generators and send it to the TSO; then sends set points to generators in order to satisfy TSO command (reactive power or voltage set point)

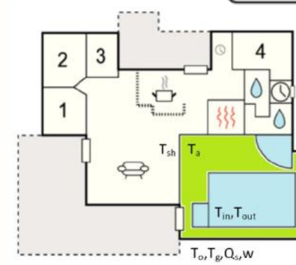
The Medium Voltage Regulation System (MVRS) aggregates active and reactive power, differentiated according to the type of energy source, calculates the virtual capability at the TSO/DSO interconnection point in order to define the active and reactive availability of the MV resources and sends set point variations in order to actuate TSO command

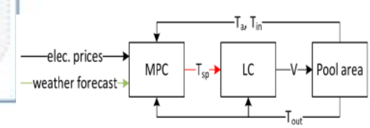
Pilot B: Ancillary services from indoor swimming pools

Common TSO-DSO AS market model







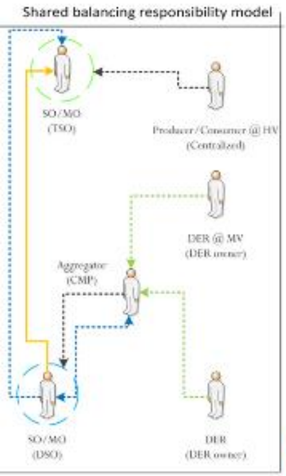


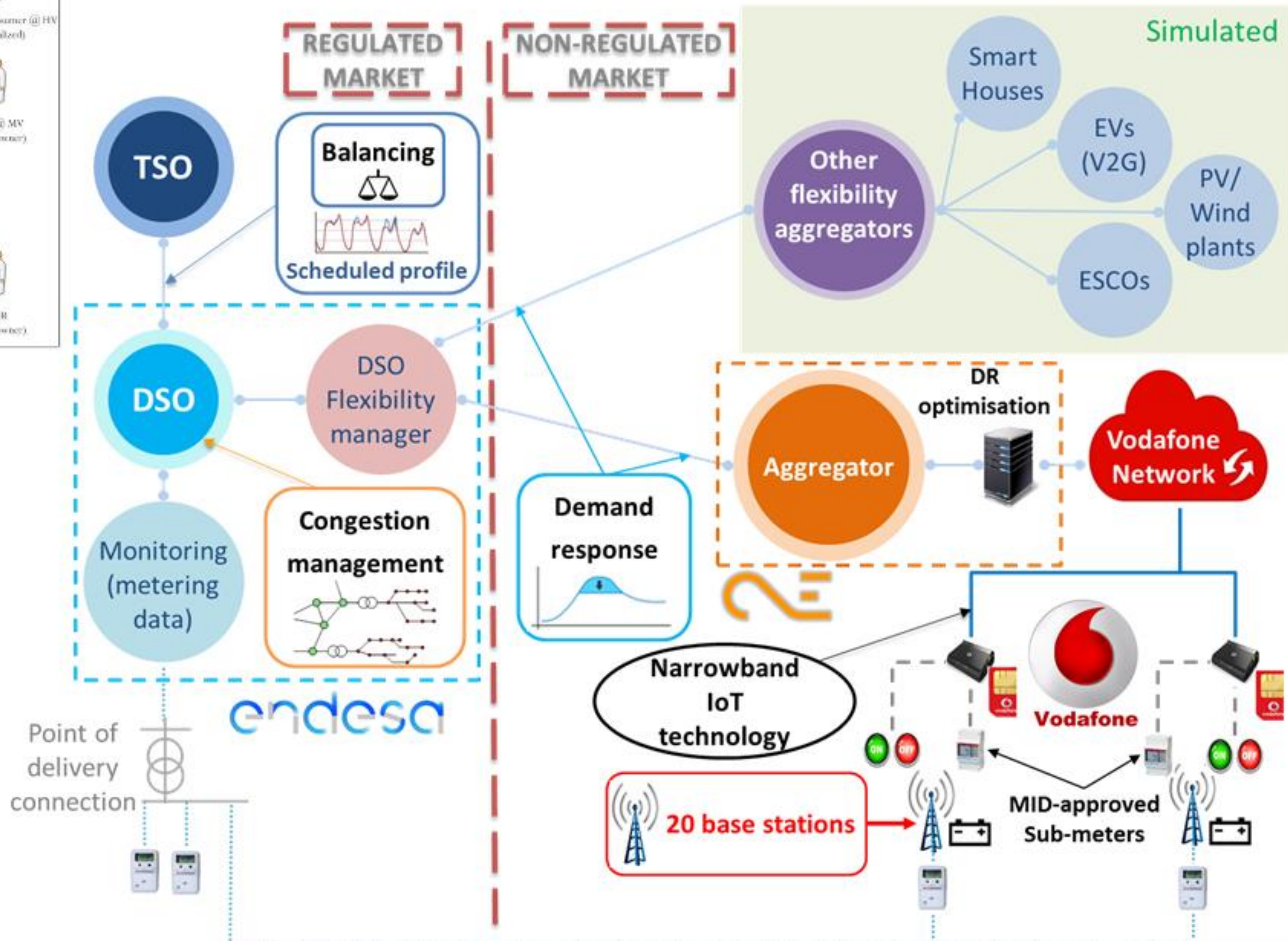
Congestion management
to better integrate PV, EV and HP

Price-based control
of thermal controllers of swimming pools in summer houses

Balancing
of wind power with decreasing contribution of thermal units

Pilot C: Ancillary services from radio-base stations



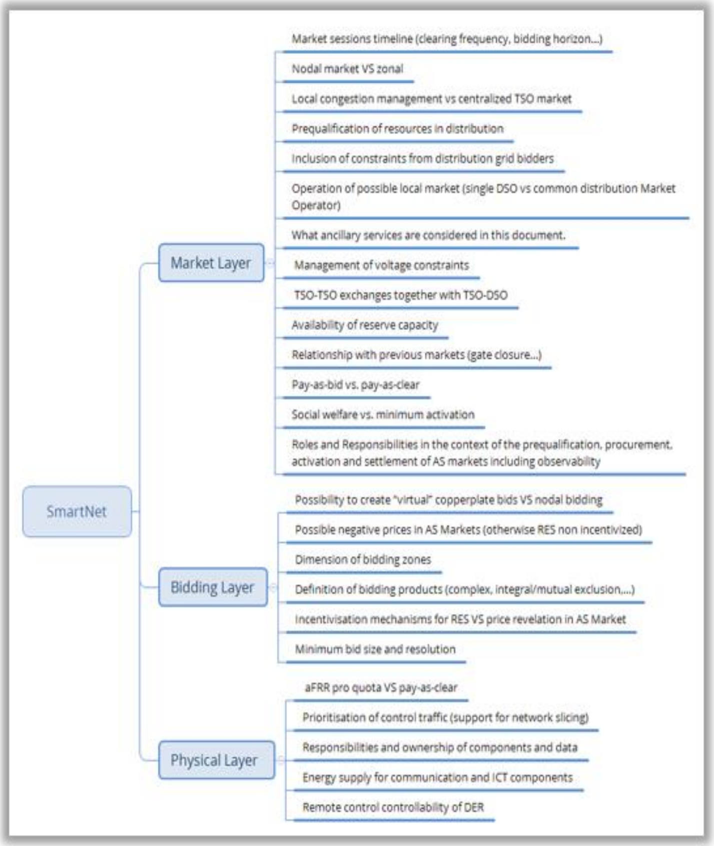


Congestion management
at DSO level

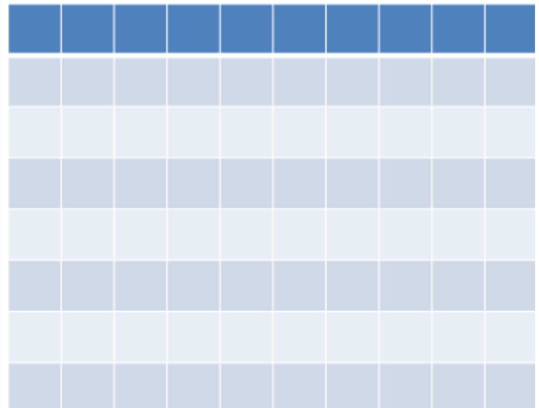
Demand Response Aggregation
by using storage flexibility (BS and EV)

Power-frequency regulation / balancing
by respecting the exchange program at the TSO-DSO interconnection

Regulatory Analysis: work structure

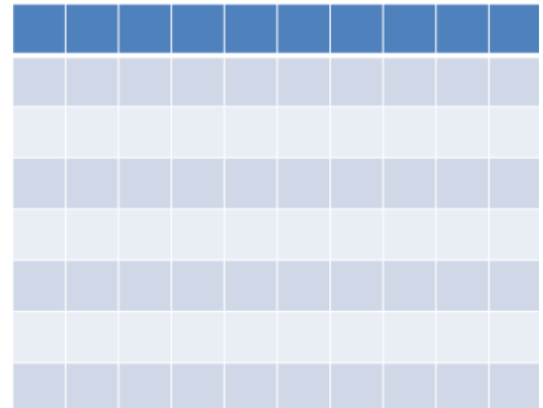


40+ regulatory documents and position papers (EU, I, DK, ES)



Deliverable D6.2

lessons learned from project activities



Deliverable D6.1

Regulatory guidelines (deliverable D6.3)

Some preliminary regulatory reflections

- If the contribution from entities in distribution will grow, DSOs should **implement real time network monitoring** and TSOs could need to **share with DSOs part of responsibility** for the provision of AS.
- Whatever coordination scheme is implemented, it is important that that actions taken by the **TSO and DSO don't cause counteracting effects** (e.g. between local congestion management and balancing) – see CEER Position Paper on Future DSO-TSO Relationship
- between the different AS markets, "**common marketplace**" (see ENTSO-E working paper on Distributed Flexibility and the value of TSO/DSO cooperation) is preferable in order to avoid duplicating bids and avoiding double activations.
- before implementing a separate market for a given AS, it should be attentively considered if it can be **sufficiently liquid** (e.g. local congestion management in distribution).
- restructuring national AS markets should take into account possibility of a **seamless integration with preceding energy markets** (DAM, ID) so as to avoid providing gaming opportunities (e.g. between non-nodal energy markets and nodal AS market)
- new AS architectures should **integrate with on-going transnational integration process** (ENTSO-E platforms): sharing reserve between Countries is a key for allowing further RES integration.
- a **balance** has to be sought for between local optimality (e.g. for a given Country) and the implementation of a harmonized pan-European design.
- **smaller DSOs have to integrate their efforts** in order to be fit for the new responsibilities.
- **real-time market architectures** must take into account the characteristics/constraints of the potential flexibility providers connected to distribution grids
- **aggregators** must be able to provide a simplified interface towards the market, hiding details of flexibility providers, and deliver efficient price signals to incentivize participation from distribution.
- **viable business models** must be available for all market participants, including DERs, aggregators and other customers.
- **network planning** will also have to facilitate better utilization of RES exploiting flexibility.

SmartNet-Project.eu

Thank You

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