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

Conclusions from national tests/simulations and their evaluations

D6.1

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About SmartNet

The project SmartNet (http://smartnet-project.eu) aims at providing architectures for optimized interaction between TSOs and DSOs in managing the exchange of information for monitoring, acquiring and operating ancillary services (frequency control, frequency restoration, congestion management and voltage regulation) both at local and national level, taking into account the European context. Local needs for ancillary services in distribution systems should be able to co-exist with system needs for balancing and congestion management. Resources located in distribution systems, like demand side management and distributed generation, are supposed to participate to the provision of ancillary services both locally and for the entire power system in the context of competitive ancillary services markets.

Within SmartNet, answers are sought for to the following questions:

- Which ancillary services could be provided from distribution grid level to the whole power system?
- How should the coordination between TSOs and DSOs be organized to optimize the processes of procurement and activation of flexibility by system operators?
- How should the architectures of the real time markets (in particular the markets for frequency restoration and congestion management) be consequently revised?
- What information has to be exchanged between system operators and how should the communication (ICT) be organized to guarantee observability and control of distributed generation, flexible demand and storage systems?

The objective is to develop an ad hoc simulation platform able to model physical network, market and ICT in order to analyse three national cases (Italy, Denmark, Spain). Different TSO-DSO coordination schemes are compared with reference to three selected national cases (Italian, Danish, Spanish).

The simulation platform is then scaled up to a full replica lab, where the performance of real controller devices is tested.

In addition, three physical pilots are developed for the same national cases testing specific technological solutions regarding:

- monitoring of generators in distribution networks while enabling them to participate to frequency and voltage regulation,
- capability of flexible demand to provide ancillary services for the system (thermal inertia of indoor swimming pools, distributed storage of base stations for telecommunication).

Partners

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List of Abbreviations and Acronyms

Acronym	Meaning
ACER	Agency for the Cooperation of Energy Regulators
AS	Ancillary Services
BSP	Balance Service Provider
CEER	Council of European Energy Regulators
CMP	Commercial Market Parties
CSs	Coordination Schemes (developed by SmartNet)
DAM	Day-ahead Market
DC	Direct Current
DER	Distributed Energy Resources
DSM	Demand Side Management
DSO	Distribution System Operator
EEGI	The European Electricity Grid Initiative
ENTSO-E	European Network of Transmission System Operators for Electricity
ETIP-SNET	European Technology & Innovation Platform - Smart Networks for Energy Transition
EUI	European University Institute
EV	Electric Vehicle
FRR	Frequency Restoration Reserve
GCT	Gate Closure Time
HV	High Voltage
IAS	Internet Access Service
IDM	Intra-day Market
ISO	The International Organization for Standardization
MO	Market Operator
RA	Reserve Allocator
RES	Renewable Energy Sources
SET	Strategic Energy Technology
SO	System Operator
SOCP	Second Order Conic Programming
TSO	Transmission System Operator
VPP	Virtual Power Plant

Executive Summary

This deliverable is one in a series of three reports that are looking into regulatory aspects of implementation of methodologies and coordination schemes developed in the SmartNet project, with the aim to facilitate integration of significant levels of Distributed Energy Resources (DERs) into the network and their participation in provision of AS at both transmission and distribution levels. This requires new market/trading architectures and operational arrangements that will affect networks at both transmission and distributions levels as well as the interface between these networks.

The aim of the SmartNet project is to provide architectures for optimized interaction between TSOs and DSOs in managing the exchange of information for the acquisition of ancillary services (reserve and balancing, voltage regulation, congestion management) from DER located in distribution networks. The main project results include the technical-economic assessment of a set of five TSO-DSO Coordination Schemes (CSs) with their market architecture. This is done through the set-up of a new simulation platform and ad-hoc national scenarios at 2030 aimed at assessing the operation of the proposed schemes so as to feed a cost-benefit analysis. The five proposed CSs are:

- Centralized AS market
- Local AS market
- Shared balancing responsibility
- Common TSO-DSO AS market
- Integrated flexibility market.

The different coordination schemes all have specific benefits and attention points related to the TSO and/or DSO grid operation, other market participants and the functioning of the market in general. In addition, implementation of or transition from one to another Coordination Schemes will require a significant change in roles and responsibilities, which are assigned to the central market actors.

As already mentioned, in order to carry out the technical-economic comparison of the different CSs, a large-scale simulator, has been developed to realistically model the behaviour of complex systems which include transmission and distribution networks, bidding and market processes, as well as fundamental physics behind each flexible device connected to the system. This simulator includes three main layers:

- Market Layer – representing the mFRR market
- Bidding Layer – representing aggregation and disaggregation processes
- Physical Layer – physical network including controls and protections and aFRR regulation

This report summarises lessons learned from the SmartNet project and discusses cross-cutting issues that are common for the proposed Coordination Schemes (CSs). These questions should be considered by national regulators when deciding on how to enable integration of DERs on a large scale and allow their

participation in the provision of ancillary services. Table 1 presents a summary of the learnings related to these cross-cutting issues that should be evaluated by national regulator, and considering the structure of national systems when deciding on the particular TSO-DSO coordination approaches.

Table 1 Summary of the learnings related to these cross-cutting issues

Layer	Topic of interest	Conclusion
Market layer	Market modelling and timelines	In the SmartNet time step has been selected as 15min, but can be changes as well as time horizon and frequency. Note that by EU regulation energy is to be traded in periods, which are at least as short as imbalance settlement (requirement of 15 min from 2025-01-01). The trade should be moved as close as possible to operation.
	Optimisation criterion for electricity market design - maximization of social welfare vs. minimum activation costs	The total cost of deploying the flexibility (procurement and activation) are minimized so to avoid unnecessary activations.
	Accounting for technical DER constraints in a market design	It is necessary to find a way to include DER constraints to enable their participation. It can be done via the market design and optimization formulation that directly account for these constrains, or to expect market participants, and in particular aggregators, to develop bidding strategies that include those constraints indirectly. In the SmatNet the physical approach (bottom-up) is preferred, and it includes the physical constraints of each aggregated technology in the aggregation models. Also, DER constraints will affect bidding products.
	Management of voltage constraints	Inclusion of AC distribution network modelling is crucial for management of voltage constraints. In the SmartNet simulator is based on Dist-flow model that allow linearization of AC power flow equations
	Pricing Mechanisms	to allow a fair and cost-efficient competition between different sources of flexibilities, in particular those located at the distribution level, the marginal pricing (pay-as-clear) approach has been adopted in the SmartNet
	Market Neutrality in the market design and proposed coordination schemes	Achieving market and coordination schemes' neutrality with respect to technology is dependent on timings and bidding rules adopted in the market designs. In the case of a central and a local market(s) in the SmartNet, the market that comes first will provide priority to procure and potentially to use flexibility from resources participating to both markets.
	Relationship with previous markets	In SmartNet the outcome of the intraday market clearing is used as the baseline for the SmartNet Markets
	Local congestion management by DSOs vs centralized TSO market	Depending on the CS, DSOs and TSOs are responsible for handling congestion in their respective grids. Balancing remains under TSOs responsibility. Centralised TSO market for procurement of resources is has higher efficiency and liquidity, but an extension to distribution could prove computationally challenging. Local markets could be illiquid and prone to exercise of market power.
	Operation of possible local market (single DSO vs common distribution Market Operator)	A number of SC in the SmartNet assume existence of the local markets. Local market in the SmartNet assumes participation of a number of market players, mainly aggregators or actors assuming this role, although larger customers can also act on their own.
	Prequalification of resources in	Prequalification and initial capacity allocation may be

	distribution networks	necessary in order to guarantee that adequate amount of flexibility is available in all relevant locations and times. SmartNet assumes that this is already in place.
	Roles and Responsibilities in the context of the prequalification, procurement, activation and settlement of AS markets including observability	Roles of the DSOs depend on the particular CS. The SmartNet models and CSs included new DSO rules that expanded the capacities of the DSOs to facilitate transparency and collaboration among stakeholders, especially cooperation between TSO and DSO
	CO_2 emissions associated with dispatching of resources in SmartNet	Emission reductions depend on the generation mix in the national system. The differences for each of the CSs are small (less than 7%). One of the main ways to reduce CO_2 is to improve efficiency of the schemes, e.g. better forecasting.
Bidding layer	Definition of bidding products	Possible to have a simple bids that will not reflect technical characteristics of DERs and their operation, leaving to the more complex market clearing algorithm to model these constraints. SmartNet project uses another approach with more complex bids that reflect constraints of DERs, but require less complex market clearing.
	Negative prices in Ancillary Services Markets	SmartNet solutions allow negative prices to reflect that flexibility can be both upwards and downwards, and also to account for subsidies
Physical layer	Types of ICT solutions and prioritization of control traffic (support for network slicing)	With the rapid increase of DERs a traffic on ICT networks may become heavy, which leads towards a question of a need to prioritize traffic needed to support power system network operation
	Responsibilities and ownership of components and data	An important issue that needs to be considered when implementing any of the CSs schemes as it is important and necessary to clearly define such roles and responsibilities are necessary. The SmartNet project assumes that legislation adequately defines the ownership and responsibilities
	ICT requirements and costs	Although ICT requirements and cost should be considered, they are relatively small compared to other costs related to CSs
	Last km ICT costs	The last km ICT costs could be a major barrier for providing ancillary services using small distributed DER and small houses making participation non-profitable
	Remote controllability of DER	At the moment lack of remote control controllability of small distributed DER is a major cost barrier for engaging them in ancillary services. These dependent on CSs and are also difficult to assess due to lack of data

1 Introduction

This deliverable is one in the series of three reports that are looking into regulatory aspects of implementation of methodologies and coordination schemes developed in the SmartNet project. Therefore, building on work related to evaluation of ancillary services, market architectures, ICT requirements and trials carried out as part of the SmartNet, the three reports seek to carry out the following analysis:

- Summarize lessons learned from evaluation of new operational tools and market models proposed and tested in the SmartNet project
- Evaluate proposed market architectures and planning and operation strategies in relation to current EU and national regulation and roadmaps developed by main industry and research bodies
- Produce a set of regulatory guidelines that reflect learning outcomes of SmartNet project

The main objective of this report is to present the learnings from the SmartNet project and summarise cross-cutting issues that are common for the proposed Coordination Schemes (CSs).

Additional evaluation of how the proposed schemes, as well as policy recommendations are discussed in the following related deliverables:

- D6.2 "Evaluation on project results related to a number of models and roadmaps ", which makes a comprehensive screening of present and forthcoming regulation with respect to some key regulatory issues that were addressed in SmartNet or influenced in some way the work in the project.
- D6.3 "Policy recommendations to implement and/or overcome barriers and enable TSO/DSO integration", which, which will conclude the work package and elaborate on the final guidelines and regulatory recommendations that result from the SmartNet project

The ever-increasing integration of Renewable Energy Sources (RES) constitutes a challenge for the pan-European electricity system, both at the transmission and at the distribution levels. This was recognised by European Commission and National regulators, who looked for possible solutions to enable RESs connections so as to help with overall environmental goals over the last decade or so. In the initial phase, issues with integration were more often related to local connection networks, rather than an overall system operation. Solutions to those issues called for changes in management of RES operation, in particular at distribution levels, but also started to include utilisation of energy storage and demand side management that could help tackling the limitations deriving from network constraints.

Further increase in DER connections has opened additional questions related to how to include them in electricity markets, and allow them, by offering flexibility, to participate in a provision of Ancillary Services (AS). Currently, AS services are mainly purchased from participants at the transmission level by Transmission System Operator (TSO). However, DERs are also seeking to participate in TSO AS markets, but these trades can be hampered by constraints that may emerge at the distribution network level due to significant increase in a number of DERs, and their influence distribution network operation. To resolve

issues at the distribution network level it can be expected that local AS markets might be needed in the future, especially if number of DREs becomes very high. This also raises a need for a better coordination between TSOs and DSOs, which is the main question addressed in the SmartNet project that evaluates five CSs to enable provision of ancillary services by DERs to both transmission and distribution network operators.

This report summarises cross-cutting issues that are common for the proposed CSs and are necessary to consider by regulators when deciding on appropriate solutions for particular national system.

1.1 SmartNet in a nutshell

Increased levels of DERs and their participation in provision of AS at both transmission and distribution levels, call for a more advanced dispatching management of distribution systems to transform distribution from a "passive" into an "active" system. Moreover, new market architectures must be developed to enable participation of DERs in energy and AS markets. New operational and trading arrangements will also affect the interface between transmission and distribution networks, which will have to be managed in a coordinated manner between TSOs and DSOs in order to ensure the highest efficiency, effectiveness and security.

The aim of the SmartNet project is to provide architectures for optimized interaction between TSOs and DSOs and help manage the exchange of information for monitoring and acquisition of ancillary services.

This section briefly outlines the main outcomes of the project - a set of coordination schemes, assumptions which were made for their implementation as well as the simulator used to assess and compare these CS.

1.1.1 SmartNet coordination schemes

SmartNet proposes five coordination schemes (CSs), each presenting a different way of organizing the coordination between transmission and distribution system operators (TSOs and DSOs), when DERs participate in provision of ASs. Here, only a brief outline for each of the CSs is provided, while their detailed descriptions are provided and discussed in SmartNet deliverable [1]. Furthermore, market aspects of the CSs are discussed in SmartNet deliverable [2].

Each of the CSs is characterized by a specific set of roles assigned to TSOs and DSOs with a comprehensive operational rules and market designs. The main differences between different CSs are related to how, and by whom, coordination of DERs' participation in AS markets or local markets is managed.

The five proposed CSs, developed within the SmartNet, are as follows:

- ***Centralized AS market model (CS-A)***, where the TSO operates a market for resources connected both at transmission and distribution levels, without involvement of the DSO and without receiving any real-time information on distribution network status.

- ***Local AS market model (CS-B),*** where the DSO organizes a local market for resources connected at the DSO-grid and, after resolving local grid constraints, offers the remaining flexibility bids to the TSO for participation in AS markets.
- ***Shared balancing responsibility model CS-C)l*** where balancing and congestion management responsibilities are divided between TSO and DSO according to a predefined schedule. The DSO organizes a local market while respecting a schedule agreed with the TSO. The TSO does the same for the transmission grid.
- ***Common TSO-DSO AS market model (CS-D)*** where the TSO and the DSO have a common objective to decrease costs to satisfy the needs for resources by both the TSO and the DSO. This mutual objective could be realized by the joint operation of a common market operated by the TSO and the DSOs,.
- ***Integrated flexibility market model (CS-E)*** *where* the market is open for both regulated and non-regulated market parties, having each a different goal to achieve (non-regulates parties would see this market as an extension of the intraday market, whereas the grid operators would procure services for the network). This scheme as not simulated because it was recognized it would pose a lot of problems (technical and regulatory) to work properly.

The different coordination schemes all have specific benefits and attention points related to the TSO and/or DSO grid operation, market participants and the functioning of the market in general. Main benefits and attention points for each scheme are summarized in the Table 2 [1].

In addition, the feasibility of the implementation of each coordination scheme is very dependent upon the regulatory framework. As discussed in [1], *Centralized AS market model* is the most in line with current regulations. The other coordination schemes would require considerable changes with respect to roles and responsibilities of TSOs and DSOs. The implementation of a coordination scheme is also influenced by the national organization of TSOs and DSOs, e.g. the number of system operators (both TSOs and DSOs) and the way they currently interact. In addition, the implementation of certain coordination schemes will have an impact on other markets, such as the Intraday markets. Dependent on the services offered in the AS market, and compared to the Intraday markets (IDM), these markets might be able to co-exist or alternatively, may need to be integrated.

Table 2 Summary of the benefits and attention points for SmartNet Coordination schemes [1]

Coordination Scheme	Benefits	Attention points

Centralized AS market model	● Efficient scheme in case when TSO is the only buyer for the service ● Having only one market is low in operational costs and supports standardized processes ● The 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 in using local flexibility ● DSO actively supports AS procurement.	● TSO and DSO markets for services are cleared sequentially ● Local markets might be rather illiquid ● Need for extensive communication between TSO market and 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 DERs	● Total amount of AS to be procured by TSO and DSO maybe higher in this scheme ● BRPs might face higher costs for balancing ● Small local markets may not be liquid enough to provide sufficient resources for the DSO
Common TSO-DSO AS market model	● Total cost of AS for TSO and DSO are minimized ● TSO and DSO make optimal use of each other	● 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 relative low prices due to large number of buyers and sellers.	● Independent market operator needed to operate the grid. ● Negative impact on the development and liquidity of intraday markets. ● TSO and DSO need to share data with Independent Market Operator (IMO).

1.1.2 SmartNet simulator

A key part of the SmartNet is a large-scale simulator, which is developed to realistically model the behaviour of complex systems which include transmission and distribution networks, bidding and market processes, as well as fundamental physics behind each flexible device connected to the system. As illustrated in Figure 1 [3] the SmartNet simulator comprises of three main layers, briefly describe below.

The Market layer

The core of the simulator is an optimization algorithm responsible for simulating the real-time balancing market clearing process. It is designed to manage large optimization problems including the constraints of all the networks and the different TSO-DSO interaction models. Modelling in this layer includes:

- **Network representation -** the market-clearing algorithm embeds a DC-power flow model for the transmission network and an approximated AC-power flow model (based on convexification of the AC power flow equations) for the distribution grid that includes complex voltages and powers [4]
- **Market products -** typical multi-period and logical constraints of flexibility providers
- **Arbitrage opportunities -** between cascading markets (i.e. day-ahead, intraday, AS market).

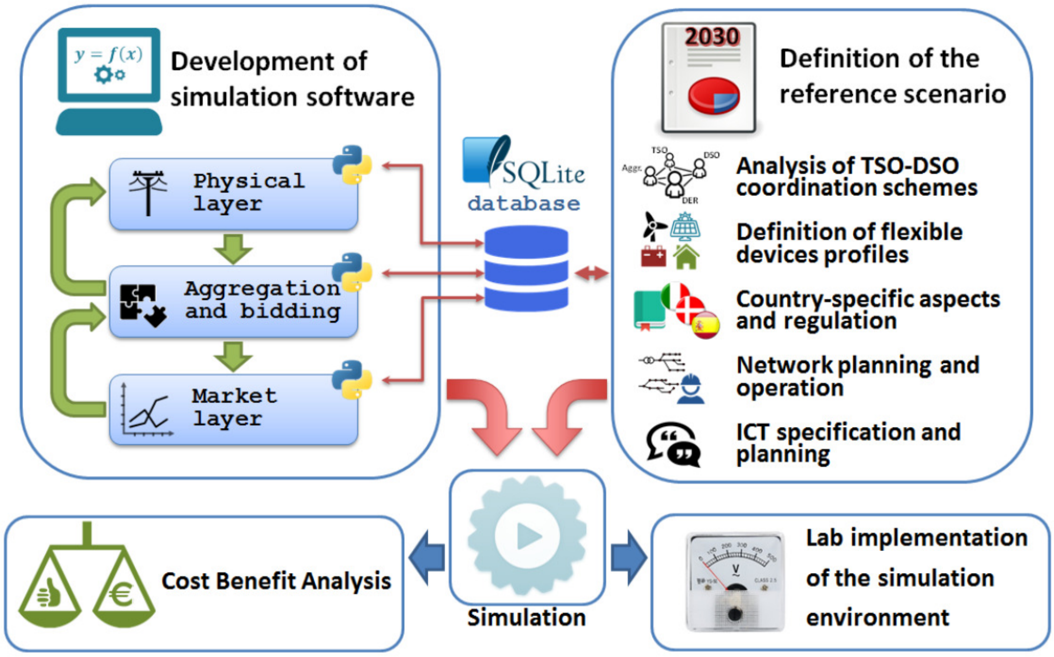

Figure 1 Structure of the SmartNet simulation platform [3]

The Bidding and dispatch layer

The interface between the physical devices and the market (and vice versa) is simulated through aggregation and disaggregation processes aimed at optimally managing the available flexibility from many dispatchable devices. This is done in order to bid the flexible devices by submitting bids that reflect flexibility costs and other constraints of particular technologies while also taking into account the potential arbitrage between different markets.

The Physical layer

The basis of the entire simulator is represented by the physics of the system components. The complex behaviour/characteristics of each network (transmission and distribution), loads, generators and flexible devices (storage, electric vehicles etc) are simulated together with the automatic processes directed by grid operators (state estimation/forecasting, network asset management etc). The processes include voltage regulation, reactive compensation, aFRR and network protections.

1.1.3 SmartNet assumptions and parameters

During the initiation of the project several important assumptions and decisions (were made regarding the types of AS, their time-scales, as well as bidding and other technical parameters. These assumptions will be summarised together with the particular issues discussed within this report.

2 Methodology

The objective of this report is to provide learnings from the SmartNet project and help others seeking to address issues related coordination between TSO and DSO that may arise due to integration of high levels of DERs and their participation in provision of ancillary services. In contrast to report [5] on Policy recommendations to implement and/or overcome barriers and enable TSO-ISO integration, which carries out analysis of result for each of the CSs evaluated in the SmartNet project, this report seeks to discuss and highlight cross-cutting issues that are important to consider when seeking to address related to TSO-DSO coordination due to increased levels of DERs. Understanding these issues is an important step for any national regulator which needs to decide on the solution that are most suitable for its system. Similarly to approach used in report on Evaluation on project results related to a number of models and roadmaps [6], this report has selected a number of aspects of the CSs that would be important to consider by national regulators.

3 Discussions on learnings from the SmartNet project

3.1 The market Layer

3.1.1 Market modelling and timelines

In the SmatNet market, the model developed and implemented sought to enable mechanisms which will help DERs trade their electric power and energy in ancillary services. Depending on the adopted coordination schemes, these services can be provided to TSO and/or DSO, but the simulator, and its market design have been developed to handle DERs' trades with both TSO and DSO . The simulator is

based on a hierarchical design formulated as standard constrained optimization problem that clears the market based on bids submitted by market participants, [2].

The SmartNet project considers and models flexibility market, here called "Integrated Reserve Market", which aims to resolve real -time imbalances and congestions between gate closure of intraday markets and real time until the opening of the next intraday market session.

Due to nature of the market and trades, i.e. intraday market for flexibility, as well as technical characteristics of the DERs, the following aspects of the market design and operation are considered when deciding on the SmartNet market design and the simulator:

- **Time step:** Considered time granularity for the market clearing. Activation decisions are made for each time step and the behaviour of the system and the flexibility assets inside each time step are considered constant at their average value.

- **Time horizon:** Overall time period considered for the market operation and clearing. The time horizon can be equal to or greater than the time step. However, it will typically be a multiple of the time step in order to model intertemporal constraints and to clear the market with some anticipation on the future time steps.

- **Frequency of clearing:** Defines how often the market is cleared. From a network balancing perspective, the market needs to be cleared sufficiently often in order to take into account the latest updated data from the system state. From an algorithmic perspective, the frequency of clearing needs to be sufficiently low, so that the optimization algorithm used to clear the market can generate (near) optimal solutions within the allowed time. If a higher frequency is required, e.g., for security reasons, an economically sub-optimal solution can be acceptable.

In the SmartNet simulator, time steps, time horizon and frequency of market clearing are parameters that are controlled by the user, providing necessary flexibility to adjust market operation and clearing for the particular conditions that will typically be dependent on regulatory settings.

For example, in simulations carried out to evaluate five CSs time step has been selected as 15min. Note that from 1st January 2025, the imbalance settlement period should be 15 minutes in all control areas. Since Market Operators (MOs) on the Day-ahead Market (DAM) and IntraDay Market (IDM) shall provide the opportunity to trade energy in time intervals which are at least as short as the imbalance settlement, energy will be traded in at least 15min period from 2025.

In Spanish Pilot market clearing frequency was set to 5 minutes, while bidding horizon was 1 hour. A vision coming from discussions of partners involved in the Spanish pilot, and also under the discussion of Network guidelines, is that the frequency should be 5 minutes or less, to be as near to real-time operation as possible. On the other hand, learnings related to the Danish Pilot project were in the direction of increasing frequency of clearing from 5 to 15 minutes.

Further considerations

In addition, some issues that were outside of the scope of the SmartNet work were identified, and should be considered when deciding on the market design for flexibility provided by DERs. These include:

- **Latency issues**: overly hierarchical organization of the ancillary service markets increases latencies and thus may reduce both the stability of the ancillary services and the value of distributed resources in the provision of these ancillary services. This also can increases the requirements on the capacity, reliability, resilience and availability of ICT (e.g. market clearing solvers, aggregation of DER flexibilities to the ancillary service markets, last km communication, etc.). While SmartNet has implemented mainly centralized system operation and markets, one of the questions looking into as part of the future work would be whether, and to what extent, the SmartNet system can be divided into autonomously operating parts that do not fail if another part of the system fails to complete in the required time. It would be important to understand and evaluate how to managing these vulnerabilities what are possible costs associated with them. Regarding the ICT operation, two important questions arise:
    - Which ICT processes need to happen in series and synchronized, and need to wait for the completion of some other processes?
    - Which ICT processes are or could be designed to run asynchronously in parallel?
- **Frequency of market clearing vs. accuracy of results:** it is important to understand and find a "sweet spot" between frequent market clearing and obtaining sufficiently accurate results (e.g. deciding on the levels of bid complexities and/or size of the market and a network) is important both from the operational and regulatory perspective. This means that a trade-off between accuracy and speed of solution will need to be evaluated, and will depend on regulatory requirements, but also on the technology of DERs that are participating in the market, as well las the size of the market/network that is considered.
- **Inclusion of a rolling horizon in the market clearing**: Rolling horizon has not been implemented in the SmartNet, but can be introduced to address stochastic behaviour of DERs, and help better passion market clearing outcome to adjust for this uncertainty. For example, for the market which is a closed-gate auction, the clearing frequency is chosen close to real time, e.g., every 15 minutes. The output of the first time step is a firm decision, which defines the actual resource activation and has to be followed by the agents (aggregators, TSO, DSOs). Implementation of the rolling optimization approach means that the optimization window (or horizon) contains several time steps (for example, one hour ahead), with solutions provided for the next time steps being advisory decisions. They will assist the agents (aggregators, TSO) to anticipate the availability of resource flexibility in the upcoming time steps, but might be subject to change. Including a rolling horizon, however, will have an impact on the definition of the optimization problem to be solved, and will also increase a time to find market clearing outcome. While the outcome will be different compared to the non-rolling horizon case, it can be expected that the benefits of such approach will be better

planning for the utilization of flexibility and reduced error, i.e. unwanted measures, for the overall time horizon.

- **Understanding behaviour of market participants**: When developing market designs and rules, it is important to investigate how participants will behave once they start learning from previous rounds of market clearings. In particular, it is important to understand when and where there may be a potential to exercise market power, and if so, when and where this may happen. This will require additional models, such as agent based modelling or bi-level optimization models.

3.1.2 Optimisation criterion for electricity market design - maximization of social welfare vs. minimum activation costs

The market objective function can be defined in several ways, targeting various economic and environmental measures, as discussed in [2]. The most common economic objectives (which are utilized in other energy and ancillary markets) are minimization of activation cost and maximization of social welfare, with the latter preferred by the EU regulators. The former aims at reducing the operating cost of the grid operator which is responsible to solve grid problems using the market product, while the latter is designed to increase the welfare for both sellers and buyers of flexibility.

In the SmartNet the approach towards the procurement of ancillary services is that the total cost of deploying the flexibility (procurement and activation) are minimized. From the mathematical point of view, the objective function is defined as maximizing the welfare by avoiding unnecessary activation. This means that only activations that contribute towards releasing congestion or voltage violations will be used, while ensuring that arbitrage bids that may even seek to induce a need for flexibility which will be solved by another bid are avoided.

3.1.3 Accounting for technical DER constraints in a market design

When deciding on modelling technical capabilities and responses from different DERs, it is important to consider how to include these into the market model. Thus, it is necessary to decide which constrains should be included in the market model, and how market participants should account for technical constraints of different DER technologies. One approach is to allow for the market design and optimization formulation to directly account for these constrains, while the other is to expect market participants, and in particular aggregators, to develop bidding strategies that include those constraints indirectly. For example, the question is how to model ramping, binary states of some devices, or, in the case of ICT, duration, size, response latency and activation time.

In SmartNet, five technology specific aggregation models, aimed at separate DER categories, have been used in order to reflect physical constraints of the devices being aggregated, as summarised in Table 3 (with more details provided in [7]). The physical approach (bottom-up) includes the physical constraints of each aggregated technology in the aggregation models, and assumes that that the aggregator knows the parameters of each individual device and its real time status. As indicated, in Table 3, the physical i.e.

bottom-up, approach has been selected as the preferred aggregation option in the SmartNet market design [7]. Other aggregation approaches have been used only in two of the models due to physical characteristics of the aggregated devices, the number of the individual devices being aggregated and the availability of data. For example, in the case of atomic loads, which use load profiles and associated costs, rather than directly defined constraints, traces aggregation approach has been used, while justified approximation (hybrid) approach, which represents the entire population of aggregated devices by a single or a limited number of virtual devices has also been used for aggregation of TCLs.

It is also important to note that the way in which technical constraints of DERs are accounted for in the market design will directly influence the definition of bids, i.e. products, used by market participants, and in particular aggregators. This will be further discussed below, in the section 3.2.1 on bidding layer.

Table 3: Aggregation approaches, types of bids and units used for aggregation of different DERs 7,8[]

Models	Aggregation approach	Type of bid	Units used
Atomic Loads	• Traces	• Non-curtailable UNIT bid[1]	• P [W], t [min], C [€]
Combined Heat and Power (CHP) Units	• Physical	• STEP curtailable Q-bid[2]	• P [kW], t [h], C [€]
Thermostatically Controlled Loads (TCLs)	• Physical • Justified	• STEP non-curtailable Q-bid • STEP non-curtailable Qt-bid	• P [W], T [°C], E [J], t [s], C [€]
Electric Energy Storage (EES) Units	• Physical	• STEP curtailable Q-bid • STEP curtailable Qt-bid	• P [kW], E [kWh], t [h], C [€]
Curtailable Generation and Curtailable Loads	• Physical	• STEP curtailable Q-bid	• P [kW], t [h], C [€]

3.1.4 Management of voltage constraints

In addition to technical constraints of DERs, it is also important to include limitations of the power network into the market model. Whereas DC approximation which neglect voltage issues can be used for transmission network operation, this type of approximation does not give accurate results for the distribution networks, where full AC network flow models are typically used.

[1] The non-curtailable UNIT bid [D2.4] represents a pair of quantity and price that does not allow for the fractional acceptance of the bid. The bid is either fully accepted or rejected

[2] The STEP curtailable Q-bid [D2.4] defines an aggregated curve of flexibility with varying marginal cost for a single time step. It provides a vector of pairs of quantity Qs and price Ps along the Q-axis and has a single price for a range between two quantities. The market operator can accept any value between two quantities

However, modelling of non-linear constraints, and in particular combined with the binary variables, is computationally challenging task. To enable utilization of existing solvers and provide computational tractability, modelling of the distribution network in the SmartNet simulator is based on Dist-Flow model. This has enabled inclusion of realistic physical models of the distribution system networks into a market clearing algorithm, providing more accurate market clearing solutions that respect physical constraints of networks and DERs . Further details on the justification of why SCOP has been selected are presented in [2]. On the other hand, for transmission network linearized DC model is applied as it provide sufficient accuracy for those networks

Therefore, modelling adopted within the SmartNet market clearing for the provision of ancillary services takes into account voltage and power flow constraints Including of these constrains within the clearing procedure enables one-step solution that will avoid selecting resources which can actually case network issues, and helps avoid countertrading and the associated costs.

3.1.5 Pricing Mechanisms

In general, there are two main pricing methods that are used in electricity markets, and both were initially discussed for the implementation in SmartNet [2]. These are:

• The "*Pay as bid*" approach where the activated bids simply receive the price corresponding to the activated quantity in the bidding curve. This approach is simple and intuitive for the different market stakeholders. However, it does not give incentive for the market participants to bid using the real cost of flexibility, creating an economic distortion in the activation decision.

• The "*Pay as cleared*" or marginal pricing approach where the activated bids receive the same price per MWh (or MW over a time step), corresponding to last activated/most expensive flexibility. This approach removes the risk of market participant bidding in terms of what they want to receive instead of their real cost of flexibility, as bidding at the true cost is considered best.

As the motivation of the designed market is to allow a fair and cost-efficient competition between different sources of flexibilities, in particular those located at the distribution level, the marginal pricing approach has been adopted in the SmartNet [2]. However, as the considered power system is not a perfect copper plate, network constraints, both at the transmission and distribution levels, have to be taken into account. Marginal pricing can be adapted to a system with network constraints in different ways:

• A *Nodal* approach where a price for flexibility is associated to the most granular level in our network representation i.e. to each node of the distribution grid

• A *Zonal* approach where a price for flexibility is associated to a zone covering different nodes. Each zone can have a different price but the nodes in the same zone have the same price. There are no constrains within one zone, just between different zones.

In the SmartNet market model, the price received per activated bids is determined through the market clearing, Although, in general, market participants can submit any bid, and not just the true costs, economists suggest that under perfect market conditions the best strategy is for them to submit true costs as it will increase the chance of being selected, while the difference between the clearing price and true costs would yield a profit. However, bidding of market participants is not under control or regulated (unless under special circumstances, such as exercising market power), which means that they can submit bids that deviate from true costs. Under pay-as-bid pricing, bids have to include a profit margin as payments and revenues are equal to the submitted bids.

SmartNet market clearing yields Locational Marginal Prices (LMPs), although it can be simplified as in the Spanish Pilot where zonal pricing is applied so that each feeder from a substation being a zone. Although evaluating different pricing approaches was not in the scope of the project, it is important to note that liquidity in the AS market, especially at the distribution local level, may be a problem if there are if the area of the local market is too small in comparison with the available bidding resources s. This can then affect the price and these issues need to be recognised and alternative pricing mechanism considered.

In addition, note that in the SmartNet market model [2], there is a price for both upward and downward flexibility (e.g. Euro per kilowatt) for each node at the level of transmission or distribution networks,

3.1.6 Market Neutrality in the market design and proposed coordination schemes

One of the main influences on achieving market and coordination schemes' neutrality with respect to technology is dependent on timings and bidding rules adopted in the market designs. In the case of a central and a local market(s) in the SmartNet, the market that comes first will provide priority to procure and potentially to use flexibility from resources participating to both markets. Assuming that the market design is a monopsony (i.e., only one buyer), there are two potential arrangements: 1) one market comes before the other – situation above explained; 2) both markets run with the same frequency and bidding horizon – in this situation, bidding rules are key, e.g., not allowing bidding in both markets.

3.1.7 Relationship with previous markets

It is important to define the related markets, the timing and which effects they have on each other, hence how the price signal from one market can affect the participation and result in the next one. As defined in the [3], different market layers are defined as follows:

Day Ahead Auction: The next trading interaction is represented by the day-ahead auction (also known as spot market), which typically closes up to 24h before the day. Since the forecast (of both production and consumption) begins to firm up, each player must place the expected exchange profile alongside with eventual complex restrictions. The matching of traded consumption and production determines a price for each time block corresponding to the baseline price for electricity in the given time

period. According to the clearing results, the same participants can then develop their trading strategies for the following markets according to their expectations on price evolution.

Intraday: The intraday market is targeted to be a trading mechanism, aimed at providing participants with an opportunity to rebalance their position in case of deviations with respect to day-ahead profiles (in order to reduce their imbalance exposure). Intraday markets play an important role since, as forecasted profiles are becoming more and more accurate by approaching the interested time slot, they "price" the most updated grid circumstances (i.e. wind or solar production under/overestimation, outages in conventional power plants, consumption pattern deviations, etc.). Currently, intraday is normally arranged as bilateral market, where participants can transparently propose and see posted prices, make and accept bids, hence playing a central role in revitalizing the "market price signal". These markets open shortly after the day-ahead auction closes and trades can then be made continuously until the market closes shortly before delivery (gate closure). The latency between intraday gate closure and beginning of delivery is called "intraday lead-time" and it is a fundamental piece of the discussion, as it sets the time horizon in which no further intraday market actions are possible. In this time interval, unforeseen events and any deviation from the program (nomination) is considered an "imbalance", unless it results from an activation in the next market (ancillary service).

As discussed in [6] several initiatives are ongoing in Europe to promote further harmonization and integration of the EUs internal energy market. The market coupling of day-ahead markets is close to being finalized and the coupling of intraday markets is ongoing. This evolution of the intraday market is in particular relevant for the Integrated flexibility market model. In principle, both the intraday market and the Integrated flexibility market model could co-exist as long as they complement each other. That is, different services are offered in each market. However, in case the same services are traded in both markets, it is more efficient to integrate both markets while extending the scope of current intraday markets, i.e. allowing for trades closer to real-time.

In Smartnet the outcome of the intraday market clearing is used as the baseline for the SmartNet Markets [2]. Historical data is used to understand the outcome of previous market (day-ahead, intra-day, etc.) as well as previous activations of the Integrated Reserve market (up to the current time step). Therefore, the consecutive chain of intraday and SmartNet markets are correlated as discussed in [8]. The correlation between consecutive markets' clearing prices has been considered in the form of an artificial cost introduced by the aggregator. This is a non-technical opportunity cost, representing the possible additional revenue of near-future flexibility activation. It is added to the other costs, in order to form a bid price for the next consecutive market. This cost variable is intended to stop the aggregator from limiting its choice only to the first opportunity in the market, disregarding the future (potentially better) value of a limited number of available activations. In other words, this cost makes the aggregator indifferent between an immediate activation and the one in the future at a better profit. This brings out two implications regarding the opportunity cost:

- it is always non-negative, and
- it is proportional to the higher expectation of the future activation.

3.1.8 Local congestion management by DSO vs centralized TSO market

One of the major questions related to TSO-DSO interactions is how local congestion at the distribution level, often caused by DERs and their participation in provision of AS, should be managed, i.e. should it be under the DSO or TSO responsibility. This is the main question addressed by five SCs proposed and evaluated in the SmartNet project, which look at both centralised and decentralised types of architectures.

There are two main variants of the market clearing: one-step and two-step procedures. Coordination schemes A and D have one step procedure, the difference is that in CS-A,

In the one-step centralized approach, the TSO, TSO and DSO together, or the market operator in general, take the activation decisions for flexibilities offered, not only at the transmission network level, but also at the level of the distribution networks. There are various degrees and ways in which DSO is involved in these schemes, and the new roles of DSOs are discussed in the subsequent section 3.1.9.

For example, in CS-A, the TSO clears the global ancillary services (Integrated Reserve) market without explicitly taking into account the models of the distribution networks. It is possible to consider such network constraints (at the lower voltage levels), but it may be computationally heavy. A blocking/veto process from the DSO is therefore needed after the market clearing during the counter-trading phase. The market clearing will not run again, but rather the counter-trading is handled outside the market, with a limited time allowed for vetoes. In case of a veto, the TSO (or the DSO) can use its own resources to compensate for the assets which are not activated. Thus, in CS-A the role of the DSO is somewhat limited. Note that in this scheme there is no-observability of distribution networks from TSO.

In a more complex CS-D the TSO and DSO co-manage the global balancing market by taking into account congestions using (simplified) models of the transmission network, but AC models also of the different distribution networks. This scheme is more computationally challenging, and requires observability of DERs and distribution networks, however results showed that it is the most efficient CS in the case when there are frequent congestions.

Two-step procedures are used in CS-B and CS-C, which yield less efficient operation and may also suffer from scarcity and illiquidity, as discussed below. Furthermore, by design, CS-C introduces additional constraint by fixing the active power exchange in the TSO-DSO interconnection thus further taking the solution away from the overall optimum. However, a benefit that may result from a two-step architecture that it can separate the system solutions and prevent spreading of high prices among the distribution and transmission systems.

Summary and list of the centralized and decentralized architectures for each CS are provided in Table 4. [2].

Table 4: List of centralized and decentralized architectures [2].

Centralized architecture	Decentralized market architecture
Centralized AS market	Local AS market
Common TSO-DSO AS market (centralized)	Common TSO-DSO AS market (decentralized)
Integrated flexibility market	Shared balancing responsibility model

If a decentralized market architecture, with two-step procedure, is used, and if the local market operators (DSOs) have to transfer the (additional) flexibility, offered by DERs or by aggregators, from the local market to the central AS market, a methodology is needed on how the DSO would perform this task. In the framework of the coordination schemes, such DSO aggregation is needed in two models: Local AS market and Common TSO-DSO AS market (decentralized). 'Readiness' of DSOs to perform these actions, be in contracting services locally and direct or on behalf of the TSO is discussed in [1]. It is assumed that DSOs are ready to perform under the described architectures however, there are fears that such arrangements may suffer from illiquidity.

Furthermore, it is also important to consider to what extent the DSOs are ready to carry out a local congestion management via a market mechanism or by contracting services and not only using their own resources. From that perspective it is necessary to recognize the importance of a number of issues related to liquidity of local markets

- How can they be ensured and/or how to overcome the problems due to illiquidity.
- A local market may create competition for flexibility resources. However, the scope of the local market dictates its liquidity.
- The timing of the sessions (local market) is a factor that impacts the liquidity of this market and the markets managed by the TSO.
- Distinction between congestion and balancing reserves and, coordinated actions (DSO-TSO) towards flexibility would help reduce competing for the resource and enhance liquidity in both markets
- Concerns that liquidity may not be realized due to the lack of advance reservation of capacity to the real time market
- Concerns over the minimum bid sizes may be too large and the bid structures too complex – liquidity issues

As mentioned above, liquidity of the local market is one of the crucial issues that needs to be resolved in order to ensure its operation. However, in contrast to wholesales and large markets, this may be more difficult to achieve both due to a lack of available resources and network constraints. It will also be important to recognise whether the illiquidity is caused by genuine lack of resources, in which case either infrastructure reinforcement of some other regulatory solutions may be proposed to improve availability of flexibility, or due to abuse of market power, in which case regulator may need to intervene, just as in the case when such problems occurs in the wholesale market.

It has been noticed that in some instances lack of flexibility may preclude SmartNet simulator to clear the market. To overcome this problem when evaluating system operation under different CSs, very expensive virtual slack-type distributed generators have been introduced. Note that utlisation of these generators will help analyse the network operation and possible issues, while in real networks this will not be a possibility. Nevertheless, implementation of transition towards CSs and local markets will have to be be preceded by detail planning studies where activation of virtual slack DGs is an important indicator of potential market issues. Note that the issue of liquidity is not related to pricing mechanisms, as it can happen both under marginal or pay-as-bid pricing.

Another important issue related to market operation and provision of flexibility is accurate forecast for availability of RES and demand flexibility.

3.1.9 Operation of possible local market (single DSO vs common distribution Market Operator)

Roles and responsibilities of the TSO/DSO/MO for each coordination scheme are outlined in [1], with Table 5 providing an overview of the most relevant roles that have to be considered in the context of the prequalification, procurement, activation and settlement of ancillary services. For each role, it is indicated which market party could take up this role.

		Role	Explanation	Adopted by
Domain	Grid operation	System Operator (SO)	Operates and manages the physical system in question	TSO; DSO
		System Balance Responsible (SBR)	Ensures the balance of the grid and reduces deviations for a system or certain area by the activation of reserves	TSO; DSO
		Data Manager (DM)	Handles grid data (incl. formatting, storage and provision), separately for each network level.	TSO; DSO; IMO
	Prequalification	Flexibility Feasibility Checker (FFC)	Responsible for assessing potential impact at distribution grid level (system prequalification) caused by the provision of flexibility-based services from a DER unit requesting participation to the AS flexibility market (central or local)	DSO
	Procurement	Reserve Allocator (RA)	Determines the amount of flexibility-based services (e.g. reserves) to be procured	TSO; DSO
		Buyer	Acquirer of flexibility-based services in a market setting	TSO; DSO; CMP
		Seller	Provider of flexibility-based services in a market setting	TSO; DSO; CMP;
		Market Operator (MO)	Responsible for setting up the market platform and operating the market	TSO; DSO; IMO

	Aggregator[3]	Collector of DER flexibility for its offering in a market setting	DSO; CMP
Activation	Flexibility Dispatcher (FD)	Activates DER units providing flexibility by sending operational signals	TSO; DSO; IMO; CMP
Settlement	Metered Data Responsible (MDR)	Responsible for measuring activated energy and for providing relevant related data to the party calculating the settlement	TSO; DSO; CMP

Table 5: Overview of roles [1]

From Table 5 new roles for the DSO are in particularly detailed with regards to variants of the coordination schemes that have decentralized market architectures. These include – the local, shared balancing and decentralized common TSO-DSO CSs, with these DSO roles detailed as follows:

Local AS Market CS - The DSO is the operator of a local market for flexibility. The DSO clears the market, selects the necessary bids for local use, and aggregates and transfers the remaining bids to the TSO-market. The DSO has priority to use the flexible resources from the local grid.

Shared Balancing CS - The DSO is the operator of a local market. The DSO contracts local flexibility for both local congestion management and balancing of the DSO-grid. The DSO is responsible for the balancing of the DSO-grid, i.e. respecting the pre-defined schedule.

Common TSO-DSO CS- The DSO is the operator of a local market. The DSO contracts local flexibility for both local congestion management and balancing of the DSO-grid. However, the TSO and DSOs are jointly responsible for the final outcome of the two separate market runs.

A number of SC in the Smartnet assume existence of the local markets, although a discussion on how they will be set up and arrived at is out of the scope of this project. Local market in the SmartNet assumes participation of a number of market players, mainly aggregators or actors assuming this role, although larger customers can also act on their own. The market clearing procedure allows the participants to submit their upwards and/or downwards bids, and the most economic ones, subject to network operation constraints, are selected to provide necessary AS. Although a size of the local area has not been investigated in this project, the size of the local market was sufficiently large to avoid market illiquidity. Nevertheless, it needs to be recognized that size of the local market (not too small but also not too large) can have a significant impact on its successful operation.

Introduction of the local market in the SmartNet may raise the important questions of their operation, including operation of network areas with multiple DSO, which vary in size and resources availability. It is also important to recognize that different countries have differed "DSO landscape" as in some countries

[3] The role of aggregator could be both performed by a CMP and a DSO. In the case a CMP or Flexibility Service Provider takes up the role of aggregator, this implies a commercial activity of collecting DER from DER owners at a certain price, which are then further commercialized in different energy markets. In case the DSO takes up the role of aggregator, there is no commercial activity involved. The DSO transfers aggregated offers, submitted in his own local market by commercial parties to the TSO.

there are relatively fewer DSOs, with other countries, such as Norway, have a very high number of small DSOs (even more then 100, as is the case in Norway). Thus, one of the important issues to recognize when discussing and deciding on the existence, structure and operation of the local markets also includes questions on what are the options for small DSOs to procure distribution services, and also how DSOs can anticipate the reaction/behaviour of the TSOs, which is relevant for a number of proposed CSs.

Regarding the issues that may occur for the small DSOs, they should define and implement a procurement mechanism for their own needs that is cost efficient [1]. They can either organize/run their own market or, if more efficient, sub-contract it (e.g., from a larger DSO). In that sense:

A local market should be established where it makes more sense. As with unbundling requirements, small DSOs (e.g., with 100k consumers or less) should not be forced to implement measures impacting their cost structure without sound reason to do so. Small DSOs should be given the option to decide if they need a local market and who the operator of such a market should be.

In addition, DSOs should be allowed to implement pilots that aim at testing different market designs and pricing schemes for services required at distribution level

3.1.10 Prequalification of resources in distribution networks

Prequalification is defined in the network codes for Load Frequency Control and Reserve as the process to verify the compliance of a Reserve Providing Unit or a Reserve Providing Group of kind FCR, FRR or RR with the requirements set by the TSO according to principles stipulated in this code [1]. However, prequalification modalities have not been studied in SmartNet, but is rather assumed to exist readily in some form. In general, some kind of prequalification and initial capacity allocation may be necessary in order to guarantee that adequate amount of flexibility is available in all relevant locations and times. Otherwise there is a risk of market failures. SmartNet concepts take into account the constraints during market clearing. Thus post qualification is not needed nor applied, as it is implied in MC processes.

The process of prequalification has been divided in two separate processes: technical prequalification and system prequalification. A technical prequalification validates the technical requirements of a unit that wants to participate to the AS market. System prequalification is defined as an up-front process where the DSO validates the participation of DER to the flexibility market, under the condition that it does not violate local grid constraints. Therefore, for the qualification of resources in distribution networks – distribution constraints must be taken into account. The DSO should be responsible for this, and in some cases already does. In addition, it is important to recognise that prequalification can have a significant impact on which DERs can participate in provision of particular services, and therefore this process has to be carefully designed not to eliminate valuable resources if they can provide these services.

In respect to ancillary services, distribution grid constraints can be taken into account ex-ante, at the time of the clearing or ex-post by the TSO. In addition, its consideration could be static, when the

constraints are considered only once, e.g., at the connection phase, or dynamic when there is a continuous check of the state of the distribution grid.

Also, a question on what are optimal ways to include distribution grid constraints in the procurement of balancing reserves can arise. Note that prequalification is critical for optimal procurement of flexibility at all voltage levels, so that in the pre-qualification phase the network operator establishes/assesses:

- Technical characteristics of flexibility providers (e.g., response times, response ramp, …)
- Metering and settlement conditions
- The aggregation level at which the network operator expects both the provision of the service and the relevant data (e.g., timing and granularity of data).
- Available volumes for procured products

This pre-qualification could be separated in technical and market (or "system") phases. In some cases, DSOs do a sort of pre-qualification to providers of balancing reserve directly connected to the distribution grid. The consideration of distribution constraints is critical for the participation of flexibility resources located at distribution grid level.

An optimal consideration of distribution grid constraints requires an active participation of the DSO in the procurement and activation process of ancillary services being sourced (in whole or in part) by distribution connected units. The need to consider distribution constraints in a static or dynamic way would mostly depend on how the distribution grid is regarded, i.e., as a copper-plate or as a grid with limited distribution capacity. If not fundamental congestions exist, then it might be "enough" to take a static approach. However, the selection of a static approach when the distribution grid has limited capacity may reduce the amount of flexibility that can be used. Therefore, in this situation it might be better to opt for the dynamic approach.

3.1.11 Roles and Responsibilities in the context of the prequalification, procurement, activation and settlement of AS markets including observability

As discussed above, Table 6 [1] provides an overview of the most relevant roles that have to be considered in the context of the prequalification, procurement, activation and settlement of ancillary services. For each role, it is indicated which market party could take up this role.

It is assumed in the SmartNet that, the DSO is always responsible for system prequalification, as further investigation of this issue was outside of the scope of this project. This process is similar across all coordination schemes.

In addition, [1] outlines in more detail how these roles of TSO and DSO relate or map to certain coordination schemes, as shown in Table 6.

Table 6 The role of the DSO in the Coordination Schemes. Source: [1].

Coordination scheme	Role of the DSO
Centralized AS market model	• Limited to possible process of prequalification
Local AS market model	• Organization of local market • Buyer of flexibility for local congestion management • Aggregation of resources to central market
Shared Balancing Responsibility model	• Organization of local market • Buyer of flexibility for local congestion management and balancing
Common TSO-DSO AS market model	• Organization of flexibility market in cooperation with TSO • Buyer of flexibility for local congestion management
Integrated Flexibility market model	• Buyer of flexibility for local congestion management

- Gradual increase of the role of DSO
- Increased level of TSO-DSO interaction

Note that the work in the SmartNet project took on board learnings from earlier EU project evolvDSO [9], which argues that roles at distribution system level will be heavily influenced by several trends, in particular by the decentralization of electricity production; increasing participation of demand response in electricity markets; growing penetration of electric vehicles (i.e., electrification of transportation); economies-of-scale and increasing acceptance of storage technologies. In addition, these trends require an enhanced collaboration between network operators, which allows an optimal allocation of available flexibility (scarce resource) among grid levels. Such a cooperation would require DSOs to adopt an active distribution system management approach. This approach allows network operators to tackle problems across timeframes i.e., planning and connection; operational planning; real-time operations; evaluation and ex post control.

The SmartNet models and CSs included new DSO rules that expanded the capacities of the DSOs to facilitate transparency and collaboration among stakeholders, especially cooperation between TSO and DSO. This can help the procurement of ancillary services by the TSO and flexibility-based services for the distribution grid by the DSO without compromising the neutrality of network operators and also help evaluate options for potential mechanisms for optimal use of system flexibility services.

3.1.12 CO_2 emissions associated with dispatching of resources in SmartNet

Reduction of CO_2 and other greenhouse gas emissions is one of the main goals of the EU energy policies addressed in a number of energy packages and polices, including the latest Energy for All Europeans [12,13]. It is a main drive behind the utilisation of RES and further development of and integration of DERs. Therefore, it is important to evaluate to what extent TSO-DSO coordination schemes can help with CO2 reductions.

One of the important learnings from the analysis carried out in [10] is that emission levels should be considered on their own, rather than including them in the costs associated with the provision of services, as this would lead to double counting. In addition, comparison of results for each of the CS reveal, as expected, that emission reductions depend on the generation mix in the national system. However, the differences for each of the CSs are small (less than 7%), and one of the main ways to reduce CO_2 is to improve efficiency of the scheme, e.g. better forecasting which will reduce activation of unwanted measures.

3.2 Bidding Layer

3.2.1 Definition of bidding products

Complexity of bids

One of the important issues related DER participation in electricity and ancillary services markets is a definition of their bids (i.e. products). In general, it is possible to have a simple bids that will not reflect technical characteristics of DERs and their operation, leaving to the more complex market clearing algorithm to model these constraints. During discussion in the SmartNet project, it was concluded that another approach with more complex bids that reflect constraints of DERs, but require less complex market clearing and activation scheduling is more suitable to apply in the market simulator.

Therefore, types of bids (i.e. products), and their complexities, allowed in the SmartNet simulator are selected to so to enable modelling of technical characteristics of various technologies. There are 3 main market products (or bids) accepted in SmartNet, as defined in D2.1 [8]:

- the UNIT-bid - defined for a specific time step and is defined by a price and a quantity
- the Q-bid - defined for a specific time step and is defined by multiple pairs of quantity-price
- the Qt-bid - offer a Q-bid for a series of time steps within the market time horizon and allows the market participant expressing the availability of flexibility for the future time steps

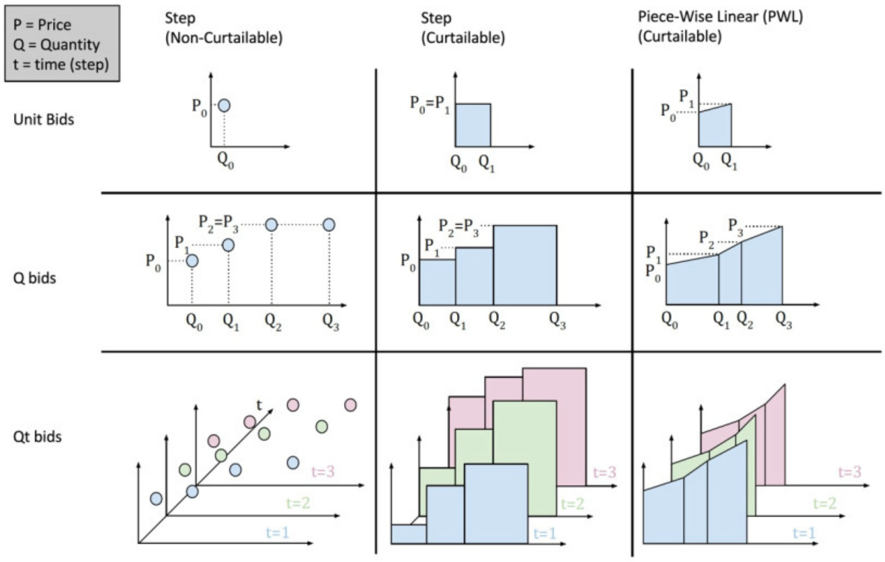

Figure 2 Different types of standard bids used in SmartNet [8]

These complex bids, illustrated in Figure 8, can be curtailable and non-curtailable, and are used by market participants (such as aggregators) to leverage the flexibility from a varied of resources as discussed in [8,5], which provides a detailed discussion on the models used. A summary of types of bids used for each of the technologies is also provided above, in Table 6. Each type provides quantity and the cost of the active power flexibility and, depending on type, also includes practical characteristics of the aggregated DERs. The models also define the bidding strategy and the type of the bids submitted to the market, as discussed in [5]

In the SmartNet market design, the aggregator offers different bidding product, which is dependent on the aggregation model, which are designed such that the aggregator is capable of providing complex bids, which incorporate integral constraint or inter-bid logical constraint (i.e. "Accept-All-Time-Steps-Or-None" constraint). These constraints are only valid for Qt bids being submitted within the market time horizon (one hour for SmartNet). Integral constraint implies that the device, for which the aggregator is bidding for, needs to be back on the (day-ahead/intraday) baseline, and is not concerned with the down/up deviations in the meantime – the asset's operation is left up to the TSO/DSO according to the flexibility needs by the system. However, the integral constraint has to consider the sum of the activated flexibility energy and the rebound energy. In a simplified approach it can be considered that for a near real-time market, such as SmartNet, its value is zero.

In practice, "Accept- All-Time-Steps-Or-None" implies that the aggregator offers entire flexibility profile, rather than a single-step independent flexibility value. These flexibility profiles include both, the flexibility period and the rebound period, in case the rebound exists. Each power profile will have a price associated with it. Since the profiles are mutually exclusive, they will be associated to an "exclusive choice

constraint." The result of the market clearing process should be either one of the offered power profiles (to be paid at the bid price or higher) or none.

Another- important aspect of the SmartNet investigation was that the range of bidding products provided in SmartNet were sufficient to model critical use cases. One of the strengths of the SmartNet project is the level of detail in the description of the bidding process and available bid types. These are described in [2]. The different bid types can be used by an aggregator or market participant to describe the range of its possibilities.

In SmartNet different types of technologies able to provide flexibility were listed in [5]. Some models employ a state-space representation and simulate the internal physics of different energy devices, such as batteries and thermostatically-controlled loads, employed in order to produce flexibility bids. Other models, such as the model proposed by Vito in section [5] are discrete models, that can be translated to a non-curtailable bid using the available bid types.

Different to the state-space models, these discrete models do not assume detailed knowledge of the connected devices, such as temperature and state of charge. Instead they assume only a given average profile, and that these loads can be deferred at the request of the aggregator. No other information is needed by the aggregator, which is useful to respect the privacy of the owner of the asset.

3.2.2 Negative prices in Ancillary Services Markets

Another important question related to market products is whether to allow negative bids. In the Integrated Reserve market of the SmartNet project, it is assumed that the assets are providing flexibility in both directions. Therefore, it is not the absolute supply and demand, but the relative increase/reduction in generation or consumption that is important. As an example, a generator reducing its generation level is providing the same type of flexibility as a consumer increasing its consumption does. These assets will both submit bids with negative quantity and are considered as downwards flexibility. Vice versa, an increase in generation or a decrease in consumption is regarded as upwards flexibility and is represented with positive bids. In that sense, terms 'supply' and 'demand' in this market.

Therefore, SmartNet solutions allow negative prices, and our experience indicates that adequate market solution need to allow for such an arrangement address subsidies and market access barriers.

As outlined in [6] bidding with negative price has been considered in several instances. It can occur in CHP unit's aggregation model, as well as the curtailable generation and curtailable loads aggregation model.

3.3 Physical Layer

3.3.1 Types of ICT solutions and prioritisation of control traffic (support for network slicing)

All communication in the CSs proposed in the SmartNet, assume that the ICT is of a sufficiently high quality so that the latency (heading towards 2/3ms) is not expected to be a problem. However, with the rapid increase of DERs a traffic on ICT networks may become heavy, which leads towards a question of a need to prioritize traffic needed to support power system network operation.

As outlined in [11] Network slicing allows the operator to provide deeply customised networks. Different requirements on functionality (e.g. charging, policy control, security) and performance (e.g. latency, mobility, and throughput) can, therefore, be realised with the same physical networks by offering dedicated network slices for different end-users.

The customer/service demands in today's communication industry are diverse and diversity will increase in the future. With network slicing, operators would be able to adapt to customer/service needs via a dedicated virtual network (=slice).

- The slice for consumers could be optimised for best-effort with the option to grant better on-demand QoS e.g. for video.
- A massive slice of IoT devices could be cost optimised and get most resources assigned in an overall low load timeframe (nights and weekends).
- The slice for autonomous driving is optimised for latency and reliability. This may be reached with computing close to the edge.
- The slice for smart metering/grid could support transport SLAs for example, via regional deployment options. High availability even in critical events (e.g. black start) can be guaranteed due to the configuration of this slice.

Each of the slices should get guaranteed resources to offer their service independent of issues present in other slices. Based on existing or future technologies, the slices should be agile to offer extra resources on demand and based on configured policies.

Technologies for prioritisation are available but commercial and regulatory barriers may prevent their utilisation. For example, the 5G mobile network technology includes network slicing, other prioritisation techniques, and possibility to use several under laying physical communication networks in parallel.

The current legislation on net neutrality forbids prioritisation on commercial reasons, but in principle allows prioritisation of control traffic that has small data amounts but needs low latencies. It is critical how the net neutrality legislation will be interpreted and implemented. Commercial network operators may be slow in taking such technologies into use that

1) are subject to interpretation of the net neutrality legislation,

2) can replace their existing high profit small segment special services

3) require that all telecom operators in the country, for example, do the same before ubiquitous services is available.

Another issue that should be mentioned when looking into implementing solutions proposed in the CSs, it whether to apply fixed or mobile ICT solutions. Mobile is seen as less expensive and more flexible, but less reliable. Flexibility of mobile solutions means more/easier access to rural areas (in terms of cost effective ways). Also, in extreme climates physical assets may be less reliable.

ICT solutions should also be considered from the perspective of the end user, and need to evaluate their willingness to pay for services, including how much they are willing to pay. This leads to a question whether end-users, in particular small ones, are in the position to evaluate which ICT equipment and services they need, which then questions their ability to make their voices heard when ICT requirement process is developed, which then may affect their costs. In addition, it is important to consider whether ICT solutions may have a negative effect on competitiveness of some DER technologies.

Finally, any solutions that depends on reliable communication and data from a large number of devices, has to consider cyber security issues. It can be argued that end-users/terminals are the weakest point in the system as they are not replacing equipment often and are less "on top" of updating the software. However, cyber security is a complex problem, and end-users should not be made responsible for the fact that they are the weakest point in the whole network. The main challenge is to define who should be responsible and how to enforce adequate measures. This can only be done in a close cooperation between DSOs, ICT providers and aggregators.

3.3.2 Responsibilities and ownership of components and data

One of the important choices related to the communication system design is the ownership of the infrastructure. Three models are possible [1]:

- Private: the network is deployed by a private party for its own use. It allows full control and access, which results in high QoS level. In WAN, the infrastructure involves high costs for both installation and spectrum acquisition, if required. It may lead to network underutilization. Private network owners in the smart grid context are normally, on the one hand, utilities, which seek to fulfil the functionalities and services linked to their business and roles, such as AMI and distribution automation; and, on the other, aggregators, building owners, etc.

- Public: operators with licensed spectrums for certain frequency range (e.g. cellular networks) offer telecom services. Problems might be a higher congestion of networks and higher security risks. However, today, most operators are able to offer Service Level Agreements (SLA), meeting more demanding requirements from clients. Unlicensed spectrums are also available for many technologies. They are free but subject to much unpredictable interference situations: QoS and availability cannot be guaranteed. Combining licensed and unlicensed spectrum is possible when both critical and less demanding functionalities are required.

- Mix of public and private: their main benefit is redundancy. Two examples of this type of networks are a private virtual network operator with no license or infrastructure but with own SIM range, billing system, etc.; and a semi-private LTE network shared with public safety.

The SmartNet project assumes that legislation adequately defines the ownership and responsibilities regarding data, and therefore does not discuss this aspect. However, this is an important issue that needs to be considered when implementing any of the CSs schemes as it is important and necessary to clearly define such roles and responsibilities are necessary.

3.3.3 ICT requirements and costs

One of the costs included in CBA are related to the cost of the ICT requirements for different coordination schemes. These analyses showed that although ICT requirements and cost should be considered, they are relatively small compared to other costs related to CSs.

Furthermore, in practice, it can be expected that the choice for a specific coordination scheme will not remain static, but will evolve with the needs of the system. Across coordination schemes, there is a gradual increase of the role and responsibilities of the DSO. Dependent on the national evolution, a country can evolve from one coordination scheme to another. In particular, the Centralized AS market model and the Common TSO-DSO AS market model share a common market architecture in terms of market platform and ICT requirements, and this may have an impact on the evolution of the TSO-DSO solutions adopted by national regulators.

3.3.4 Last km ICT costs

The last km ICT cost (communication and interfacing small DER) are not included in the ICT cost in CBA [10], as they do not change significantly with the market model as long as utilises the flexibilities of small DER. However, it should be noted that

The last km ICT costs could be a major barrier for providing ancillary services using small distributed DER and small houses making participation non-profitable under a certain minimum size. The last km ICT cost also set an even higher minimum DER size for participating in the real time.

The difference in ICT Costs between the different CSs are very small compared to the benefits of different CSs, related uncertainties and the large uncertainties related to the connecting very small DER to the aggregators. In addition, the last km ICT costs depend mainly on legislative and regulatory requirements and business decisions of commercial actors and less on the organisation of ancillary service markets. The enabling technologies are available but not yet taken into large scale use.

3.3.5 Remote controllability of DER

At the moment lack of remote control controllability of small distributed DER is a major cost barrier for engaging them in ancillary services. These costs together with the last km communication costs and other aggregation costs are much higher than those ICT costs that stem from the SmartNet market designs and depend on the coordination schemes. Only the coordination scheme dependent costs were included in the ICT cost analysis.

The development of grid connection codes (by ENTSO-E) and especially the related standards development by CENELEC (European EN standards), IEC, ISO and IEEE give justification for the hopes that by 2030 smaller and smaller inverter based DER interfaces will have standardised interfaces and functionalities for remote controllability readily implemented. For bigger DER due to grid connection requirements and for smaller DER due to the obvious benefits of using the same standards also for them.

Thus it is possible that in 2030 most distributed generation, electricity storage, microgrids and electrical vehicles have the functionalities and interfaces for remote controllability as needed by the ancillary services in general and SmartNet concepts in particular. Then the DER will have interfaces for DSOs to remotely control set points for active and reactive power and the droops for local frequency and voltage responses. It would also be very reasonable to extend such requirements and functionalities to flexible loads, too. That will mean a large drop of costs in engaging small DER to ancillary services.

4 Conclusions

This report summarizes lessons learned from the SmartNet project and discusses cross-cutting issues that are common for the proposed Coordination Schemes (CSs). These questions should be considered by national regulators when deciding on how to enable integration of DERs on a large scale and allow their participation in the provision of ancillary services. Table 8 presents a summary of the learnings related to these cross-cutting issues that should be evaluated by national regulator, and considering the structure of national systems when deciding on the particular TSO-DSO coordination approaches.

Table 8 Summary of the learnings related to these cross-cutting issues

Layer	Topic of interest	Conclusion
Market layer	Market modelling and timelines	In the SmartNet time step has been selected as 15min, but can be changes as well as time horizon and frequency. Note that by EU regulation energy is to be traded in periods, which are at least as short as imbalance settlement (requirement of 15 min from 2025-01-01). The trade should be moved as close as possible to operation.
	Optimisation criterion for electricity market design - maximization of social welfare vs. minimum activation costs	The total cost of deploying the flexibility (procurement and activation) are minimized so to avoid unnecessary activations.
	Accounting for technical DER constraints in a market design	It is necessary to find a way to include DER constraints to enable their participation. It can be done via the market design and optimization formulation that directly account for these constrains, or to expect market participants, and in particular aggregators, to develop bidding strategies that include those constraints indirectly. In the SmatNet the physical approach (bottom-up) is preferred, and it includes the physical constraints of each aggregated technology in the aggregation models. Also, DER constraints will affect

		bidding products.
	Management of voltage constraints	Inclusion of AC distribution network modelling is crucial for management of voltage constraints. In the SmartNet simulator is based on Dist-flow model that allow linearization of AC power flow equations
	Pricing Mechanisms	to allow a fair and cost-efficient competition between different sources of flexibilities, in particular those located at the distribution level, the marginal pricing (pay-as-clear) approach has been adopted in the SmartNet
	Market Neutrality in the market design and proposed coordination schemes	Achieving market and coordination schemes' neutrality with respect to technology is dependent on timings and bidding rules adopted in the market designs. In the case of a central and a local market(s) in the SmartNet, the market that comes first will provide priority to procure and potentially to use flexibility from resources participating to both markets.
	Relationship with previous markets	In SmartNet the outcome of the intraday market clearing is used as the baseline for the SmartNet Markets
	Local congestion management by DSOs vs centralized TSO market	Depending on the CS, DSOs and TSOs are responsible for handling congestion in their respective grids. Balancing remains under TSOs responsibility. Centralised TSO market for procurement of resources is has higher efficiency and liquidity, but an extension to distribution could prove computationally challenging. Local markets could be illiquid and prone to exercise of market power.
	Operation of possible local market (single DSO vs common distribution Market Operator)	A number of SC in the SmartNet assume existence of the local markets. Local market in the SmartNet assumes participation of a number of market players, mainly aggregators or actors assuming this role, although larger customers can also act on their own.
	Prequalification of resources in distribution networks	Prequalification and initial capacity allocation may be necessary in order to guarantee that adequate amount of flexibility is available in all relevant locations and times. SmartNet assumes that this is already in place.
	Roles and Responsibilities in the context of the prequalification, procurement, activation and settlement of AS markets including observability	Roles of the DSOs depend on the particular CS. The SmartNet models and CSs included new DSO rules that expanded the capacities of the DSOs to facilitate transparency and collaboration among stakeholders, especially cooperation between TSO and DSO
	CO_2 emissions associated with dispatching of resources in SmartNet	Emission reductions depend on the generation mix in the national system. The differences for each of the CSs are small (less than 7%). One of the main ways to reduce CO_2 is to improve efficiency of the schemes, e.g. better forecasting.
Bidding layer	Definition of bidding products	Possible to have a simple bids that will not reflect technical characteristics of DERs and their operation, leaving to the more complex market clearing algorithm to model these constraints. SmartNet project uses another approach with more complex bids that reflect constraints of DERs, but require less complex market clearing.
	Negative prices in Ancillary Services Markets	SmartNet solutions allow negative prices to reflect that flexibility can be both upwards and downwards, and also to account for subsidies
Physical layer	Types of ICT solutions and prioritization of control traffic (support for network slicing)	With the rapid increase of DERs a traffic on ICT networks may become heavy, which leads towards a question of a need to prioritize traffic needed to support power system network operation

	Responsibilities and ownership of components and data	An important issue that needs to be considered when implementing any of the CSs schemes as it is important and necessary to clearly define such roles and responsibilities are necessary. The SmartNet project assumes that legislation adequately defines the ownership and responsibilities
	ICT requirements and costs	Although ICT requirements and cost should be considered, they are relatively small compared to other costs related to CSs
	Last km ICT costs	The last km ICT costs could be a major barrier for providing ancillary services using small distributed DER and small houses making participation non-profitable
	Remote controllability of DER	At the moment lack of remote control controllability of small distributed DER is a major cost barrier for engaging them in ancillary services. These dependent on CSs and are also difficult to assess due to lack of data

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