Deliverable 3.3

TSO-DSO Coordination for Procurement and Activation of System Services

The ALEXANDER consortium

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"A boat doesn't go forward if each one is rowing their own way"

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Alexander

Management summary

The 2022 energy price crisis highlighted the urgent need for a resilient and affordable energy system, as the EU faces challenges in balancing renewable energy's volatility and growing electrification. Over the next years, both Transmission System Operators (TSOs) and Distribution System Operators (DSOs) will require more flexibility from all voltage levels to ensure system stability as well as to improve security of supply and balancing. In the past, only TSOs were procuring flexibility for balancing the transmission grid. However, with ongoing decentralization, DSOs are also starting to make use of different flexibility mechanisms. On the other hand, flexibility assets are more prominent in the low voltage grids and these assets can be utilized for system-wide services. Distributed flexibility, enabled by new technologies and consumer participation, will be crucial to meet EU energy policy goals of security, sustainability, and competitiveness.

As both DSO and TSO require flexibility, coordination of how this flexibility is procured and activated is of utmost importance for at least four key reasons:

- Cost efficiency: from a system-wide point of view, flexibility should be procured at minimum cost, while ensuring that there are no unnecessary or harmful flexibility activations. It also implies that market clearing mechanisms should be as optimized as possible, and market liquidity should be guaranteed.
- Value stacking: as flexibility, especially in certain locations, is scarce and local flexibility markets are still immature, it is important to ensure maximization of utilized distributed flexibility by allowing for the provision of multiple system services through participation in different markets. This implies ensuring harmonization and coordination between different markets and products, aligning different market timings, and engaging flexibility service providers (FSPs) in multiple markets.
- Grid safety: activation of flexibility resources by one system operator should not cause any harm to the grid of the other system operator. This implies a need to include grid constraints or their proxy into the market clearing mechanisms, which requires discussions and actions linked to network data and grid visibility.
- Feasibility: finally, any activity taken up in the electricity system, should be feasible and applicable in practice. This implies that the entire market process including bid forwarding should be well designed.

Both in theory and in practice, many different coordination schemes are possible. In a country such as Belgium, with many different regulations, with four different DSOs, which have different flexibility needs and different levels of maturity of flexibility markets, three different regions, thus three regional regulators, and one federal regulator, as well as one TSO at the national level, choosing between and agreeing on the different coordination schemes is challenging. ALEXANDER therefore sets up a framework (illustrated in Figure), allowing proper comparison between all the different coordination schemes that system operators can choose from based on the previously mentioned challenges and ultimately providing action points and no-regret measures for each coordination scheme.

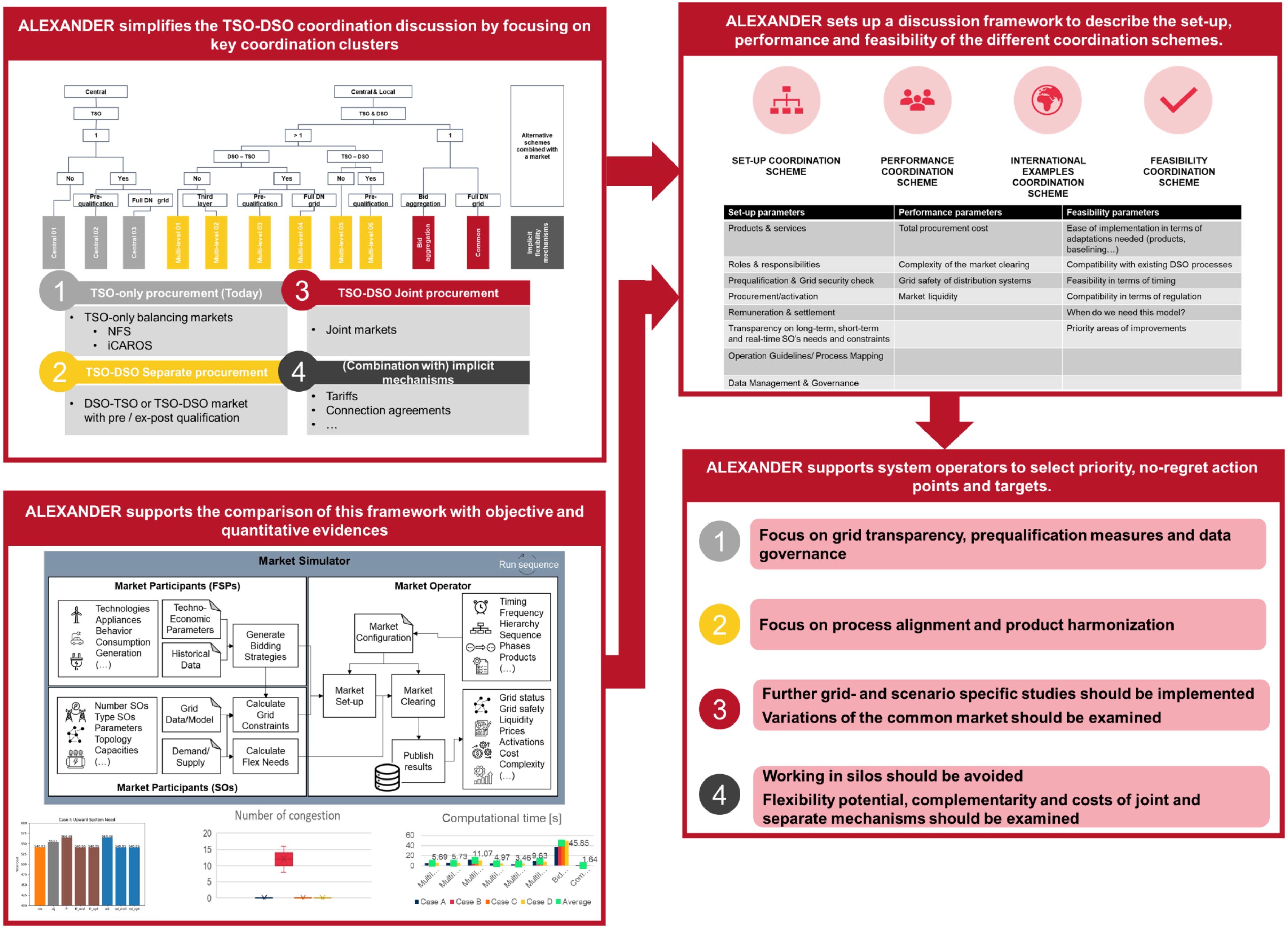

Figure: ALEXANDER framework overview

The framework set up by ALEXANDER contains 4 key elements:

1. ALEXANDER simplifies the complex comparison of different coordination schemes by clustering all coordination schemes into 4 key coordination clusters, which have different levels of market maturity as well as contextual and regulatory characteristics. The four clusters are: (i) TSO-only procurement (cluster 1), where the flexibility market is only set up by the TSO; (ii) TSO-DSO separate procurement (cluster 2), where the DSOs and TSO set up their own individual markets; (iii) TSO-DSO joint procurement (cluster 3), where the DSOs and TSO jointly procure flexibility in a co-optimized manner; and (iv) Combination with implicit flexibility mechanisms (cluster 4), where a market-based mechanism co-exists with implicit mechanisms such as connection agreements or network tariffs. ALEXANDER sets up the 4 clusters in such a way that choosing one cluster never blocks later progression towards another cluster. Clusters 1 until 3 can actually be seen as sequential clusters where system operators can move from cluster 1 (which is the business-as-usual (BAU) cluster in Belgium) toward cluster 2, in which the DSOs procure flexibility by setting up its own individual flexibility market (e.g., the market pilots of Fluvius and Ores). Afterward, one can move further towards cluster 3, in which all system operators procure flexibility jointly, for instance through one common market. The 4th cluster is a cluster that can run in parallel with the other clusters as it focuses on a combination of a market-based coordination scheme with non-market-based flexibility acquisition mechanisms. That is, independent of which coordinated market scheme is chosen, it is important that it does not conflict with existing tariff mechanisms or other methods such as connection agreements.
2. For each cluster, ALEXANDER sets up discussion tables to study the set-up requirements of each coordination scheme. The set-up requirements are described in terms of implications for the development of products and services, roles and responsibilities, prequalification and grid security, procurement and activation, remuneration and settlement, SO grid transparency, operational guidelines and process mapping, and finally data and governance. These discussion tables can be used to reach agreements between all system operators on the action points that are needed to meet the no-regret parameters.
3. In order to complete the discussion tables, **quantified evidence** is required to objectively compare different options. To that end, optimization-based mathematical market-clearing models of all different coordinated market schemes (a market simulator) are developed. This simulator captures the market clearing process, taking into account the flexibility requirements by system operators that request some flexibility provision, their grid status, and available flexibility resources in the grid. Then, the performance of these models, in terms of total procurement cost, complexity of market clearing, grid safety of the distribution system, and market liquidity are evaluated. On top of this, it is also important to **qualitatively compare** different coordination schemes by examining their feasibility. The feasibility is described in terms of the ease of implementation, the compatibility with existing DSO processes, and the feasibility in terms of timing and regulatory compatibility. It is concluded with a discussion on when this model is needed and how one should move forward to achieve it.
4. Finally, we provide our evaluation on which elements should be prioritized in terms of discussions and/or action points using colour codes. To facilitate the discussion, ALEXANDER defines no-regret key parameters that minimally need to be satisfied before the coordination scheme can work properly (however, depending on local circumstances, DSOs are free to define other/additional no-regret key parameters). Whenever the key parameters in a prior coordination scheme are met, one can move forward to the next coordination scheme. From ALEXANDER perspective, the following no-regret action points were defined:
    - In cluster 1, the DSO has limited grid visibility insights. It is of utmost importance to increase grid transparency as this will help properly prequalify assets (for any purpose) and as it ensures proper identification of flexibility needs (which is required in other coordination schemes). Furthermore, setting up proper prequalification tools is essential

when the TSO starts procuring distribution-level resources. Finally, it is necessary to ensure proper data governance to allow for data and information sharing between system operators. For instance, prequalification data need to be shared, ideally through a flexibility register. But also, with the rollout of smart meters, proper data infrastructure is indispensable to benefit from the data.

- In cluster 2, assuming that the previous no-regret parameters are in place, a DSO may procure flexibility, e.g., for congestion management. This inevitably implies that there will be multiple markets (DSO-market(s), TSO-market, wholesale markets). It is therefore important to align key processes (such as prequalification and market timing) and harmonized products while ensuring the market designs do not become too complex for FSPs. Finally, it is also important to ensure market liquidity and consumer engagement so that all parties, including customers and FSPs, can adapt their processes and move toward the same objectives of achieving efficient network operations.
- Cluster 3 is the most complex and demanding as it requires full alignment of processes and products. This cluster should not necessarily be the end goal as a trade-off is needed between the costs of setting up this scheme and the benefits this scheme achieves. To properly make this trade-off, 2 key no-regret actions should be accounted for: First of all, scenario and grid-specific analyses per grid area and/or DSO are needed to understand their costs and benefits, as no one-size-fits-all answer can be given. Secondly, the ALEXANDER project demonstrates a variation of the common market scheme that is less complex, in terms of data management, to implement yet achieves almost the same benefits for the system operator. It is therefore important to emphasize that in cluster 3, there are variations that allow for co-optimization, which results in the most efficient flexibility provision without having a common market model. Given the fact that some system operators see the common market scheme as too 'futuristic' and 'unrealistic' to implement, it is important to further examine the alternatives to the common market.
- Cluster 4 is a cluster that should be accounted for with all the previous clusters. System operators can make use of both implicit and explicit flexibility mechanisms and it is important to ensure that the objectives of these mechanisms are not conflicting. To be able to do so, it is highly recommended to further examine the flexibility potential of all the different flexibility mechanisms, both jointly and individually. These benefits should then be traded off with the implementation costs of those (combined) flexibility mechanisms. Therefore, transparency is needed regarding the complementarity of different flexibility mechanisms. As in cluster 3, it is unlikely that a one-size-fits-all solution applies, requiring tailored studies per grid area.

The ALEXANDER project contributes to the ongoing discussions on Belgian TSO-DSO coordination. However, it is important to note that completing the framework requires further dialogue between system operators, along with specific quantitative analyses based on Belgian grid data and future scenarios. These steps are essential to fully tailor the framework to Belgium's unique context. Furthermore, when both the DSOs and TSO implement flexibility mechanisms, regardless of which cluster their coordination scheme belongs to, it is highly important to have a common vision, which aligns the flexibility provision of TSO and DSOs, e.g., it should have a view of whether different flexibility needs of multiple system operators coincide and a process that deals with this possible conflict.

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Abbreviation and acronyms

AmFT	Aansluiting met Flexibele Toegang (Flexible connection agreement)
Art.	Article
BAU	Business-as-usual
CEP	Clean Energy Package
DA	Day ahead
DER	Distributed Energy Resource
DSO	Distribution System Operator
EMD	Electricity Market Directive
EU	European Union
FRP	Flexibility Requesting Party
FSP	Flexibility Service Provider
iCAROS	Integrated Coordination of Assets for Redispatching and Operational Security
ICT	Information and communication technology
ID	Intraday
IEEE	Institute of Electrical and Electronics Engineers
LFM	Local Flexibility Market
LV	Low Voltage
MARI	Manually Activated Reserves Initiative
MO	Market Operator
MV	Medium Voltage
NCDR	Network Code on Demand Response
NFCA	Non-Firm Connection Agreement
NFS	Network Flexibility Study
PTDF	Power Transfer Distribution Factors
SO	System Operator
ToE	Transfer of Energy
TOU	Time-of-use
TRDE	Technical Regulations for the Distribution of Electricity
TSO	Transmission System Operator
UTOPF	Unbalanced three-phase optimal power flow

Nomenclature

Brugel	Regulatory authority in the Brussels region
CWaPE	Regulatory authority in the Walloon region
Elia	Belgian transmission system operator
Fluvius	Distribution system operator in the Flanders region
ORES	Distribution system operator in the Walloon region
RESA	Distribution system operator in the Walloon region
Sibelga	Distribution system operator in the Brussels region
Synergrid	Federation of electricity and gas system operators in Belgium
VREG	Regulatory authority in the Flanders region (Vlaamse Regulator Energie en Gas)

1 Introduction

1.1 Context

"*The latest energy price crisis in 2022 has dramatically shown that one cannot take neither security of supply nor affordability for granted. Over the next 20 years, the EU's energy market must transform fundamentally, and the internal market needs to continue to adapt to be 'fit for purpose', to continue to drive the three overarching energy policy objectives which are security of supply, sustainability, and competitiveness*" (Borchardt, 2024). Indeed, the EU energy markets need to adapt to increasing levels of distributed renewable energy generation, which is by nature more unpredictable and volatile, and connected to lower voltage levels at the distribution grid. The EU wants to become less dependent on fossil fuels which implies an electrification of our energy consumption (electric mobility and heating). This electrification increases electricity consumption while, at the same time, renewable energy can be highly volatile, leading to energy security challenges. As a result, more than ever, flexibility is one of the key elements to ensure the success of this system transformation.

Flexibility is not a new topic as the energy system needs to be balanced every second of the day, day in and day out. However, the nature of flexibility is changing, requiring different provision approaches from existing ones. Firstly, from a flexibility demand side of view, in the past, flexibility was only requested by the transmission system operator (TSO). However, with increasing electrification at lower voltage levels (e.g., heat pumps and electric vehicles) and with increasing levels of decentralized energy at lower voltage levels (e.g., photovoltaic energy), changing consumption and generation patterns are taking place at distribution grids. This leads to increasing congestion levels and voltage issues, requiring the distribution system operator (DSO) as well to acquire flexibility. As a result, next to the traditional TSO, the DSOs are also in need of flexibility. Secondly, in the past, flexibility was only offered by resources connected at the transmission level. However, today, more and more flexibility is available at the distribution grid level due to the connection of new technologies such as batteries, electric vehicles, and heat pumps, but also due to the uptake of smart meters and digitalization in general. In addition, the Clean Energy Package (CEP) is also pushing for more consumer engagement and participation in different energy markets (for instance through concepts such as active consumers and energy communities in the Renewable Energy Directive II and Electricity Market Directive (EMD)). Finally, since distribution and transmission grids are physically connected, distribution-level flexibility resources have the potential not only to fulfil the flexibility needs of their distribution grid but also to provide system-wide services at the transmission level.

1.2 TSO-DSO coordination objectives and challenges

The above development on the flexibility requirements, resources, and procurements implies that coordination among system operators becomes even more crucial than before. As the ultimate goal is to achieve efficient and effective operation, flexibility mechanisms of all system operators must be aligned and must not conflict with each other. Figure 1-1 shows the necessary ingredients in setting up a flexibility provision mechanism, including consumer engagement, products and services, roles, regulation, procurement process, and data management. Ideally, given the current context, each of these ingredients must be coordinated among the system operators. Furthermore, (the draft of) the Network Code on Demand Response (NCDR), as listed in Table 1-1, explicitly states cooperation and coordination required by the DSOs and TSOs to solve any issues on the operation of transmission and distribution grids.

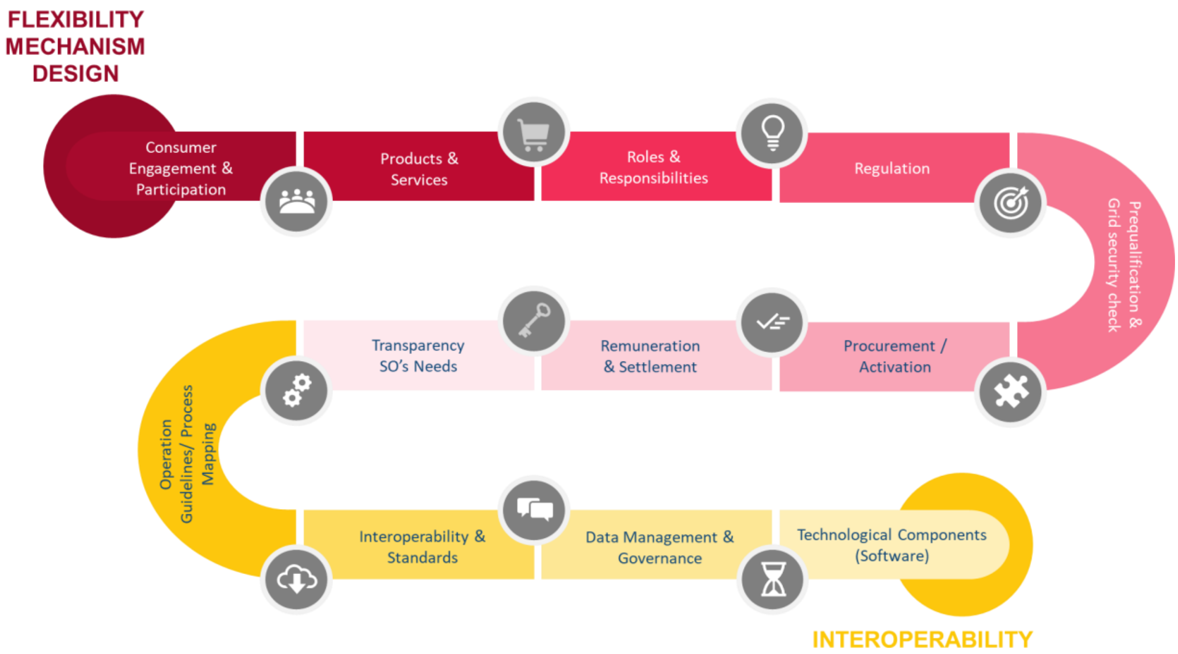


Figure 1-1: Flexibility ingredients to be considered.

Table 1-1: Requirement for coordination among system operators in the draft NCDR

Article/chapter	Content citations draft NCDR
Article 43	Coordination and interoperability between local, day ahead (DA), intraday, and balancing markets.
Article 54	1. No later than [6 months] after the approval of the national rules of procedure of a Member State pursuant to Article 4, all system operators of a Member State shall develop a proposal for national terms and conditions for TSO-DSO and DSO-DSO coordination. 2b Actions to solve balancing, congestion or voltage issues: (i) shall not create or aggravate congestion or voltage issues on other systems or regenerate problems that have been solved by actions taken by operators of those systems or endanger system security;
Article 57	2. To contribute to solving congestion or voltage issues on other grids, each system operator shall: (a) cooperate with system operators of those grids and consider grid-reconfiguration on its grid; and (b) cooperate with procuring system operators to facilitate and enable the delivery of local services by service providing groups or service providing units connected to its grid;
Article 59	Data exchange between system operators shall ensure: (a) that each system operator has access to data related to other system operators' systems, that are necessary to determine the condition of its own system, to forecast and detect congestion and voltage issues and to identify solutions; (b) the coordinated access of all system operators to all available resources to provide local and, where relevant, balancing services, and the optimal selection and activation of selected resources

Four key objectives of having proper coordination among system operators can be summarized in Table 1-2. Coordination is established to ensure that flexibility is procured in a cost-efficient manner, the potential and values of flexibility resources can be maximally utilized (value stacking), while at the same time, grid safety of the entire grid is guaranteed. Finally, the coordination process that is set up must be practical/applicable, i.e., it is coherent with regulation and its complexity is manageable. For each of these key objectives, there exist challenges that must be overcome (Sanjab, et al., 2023), and again they are related to the ingredients of the flexibility mechanism design.

Table 1-2: Objectives and relevant challenges of TSO-DSO coordination for flexibility provision

Key objective	Definition	Linked challenges
Cost efficiency	Minimum cost of procuring flexibility	- Market liquidity - Optimization mechanisms for market clearing - Baselining - Settlement
Value stacking	Utilization of distributed flexibility is maximized by allowing for the provision of multiple system services through participation in different markets	- Harmonization and coordination between different markets - Market timing - Flexibility service provider (FSP) engagement - Implicit flexibility mechanisms - Product requirements - Double activation
Grid safety	Activation of flexibility resources does not cause any harm in distribution and transmission systems	TSO needs to **account for** DSO grid constraints: - Transparency - Prequalification (method, criteria) - Counterbalancing action - Network data acquisition
Feasibility	A coordination scheme can be implemented in practice	- Platform development and implementation - Complexity of coordination - Coherency with existing regulation

1.3 Scope

This deliverable provides a study on TSO-DSO coordination for procurement and activation of distributed flexibility resources. It focuses on the operational process and market organisation, such that distributed flexibility can be efficiently procured and utilized across different system operators while ensuring the safe operation of the grid. In this deliverable, extensive qualitative and quantitative comparisons of different TSO-DSO coordinated market schemes, addressing all the coordination objectives, are provided while the analyses also put some emphasis on the Belgian context. The interplay between these market schemes with non-market flexibility mechanism is also briefly discussed.

1.4 Document organization

This report is organized as follows. Chapter 2 explains flexibility acquisition mechanisms in general as well as existing ones in Belgium. Chapter 3 focuses on coordinated flexibility procurement between DSOs and the TSO and discusses all the possible coordination options, emphasizing primarily the coordinated market designs. Then, Chapter 4 provides quantitative analyses of TSO-DSO coordinated flexibility markets while Chapter 5 discusses some quantitative analyses of non-firm connection agreement, which is an example of non-market-based flexibility provision mechanism, that can be put in place together with market-based mechanisms. Afterward, Chapter 6 evaluates qualitatively these coordination schemes and assesses their practicality in the Belgian context. Finally, some concluding remarks are provided in Chapter 7.

2 Flexibility acquisition mechanisms

To kick off the deliverable, this chapter gives a background on the procurement of flexibility for distribution system operators (DSOs).

2.1 Basic flexibility acquisition mechanisms

More flexibility from different grid levels is needed and offered by multiple stakeholders. Flexibility can be acquired through different flexibility mechanisms, ranging from implicit (rule base solutions and connection agreements, tariff-based solutions) to explicit flexibility (market-based solutions), see Figure 2-1.

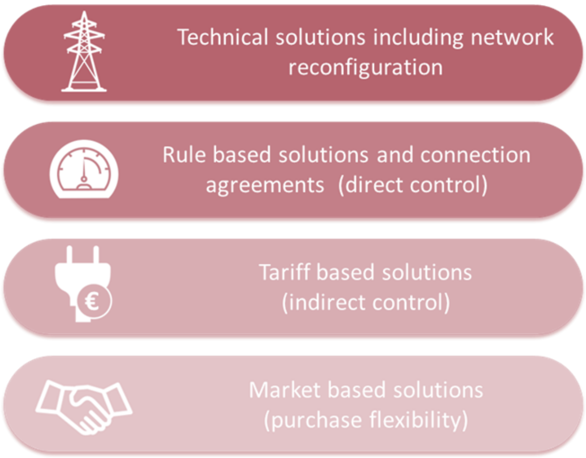


Figure 2-1: Flexibility acquisition mechanisms.

Traditionally, system operators mostly rely on technical solutions (including network reconfiguration and grid reinforcements). However, the phase out of fossil fuels goes hand in hand with more electrification and renewable energy, leading to significant challenges for our electricity grids. Europe recognizes this challenge by putting in place a grid action plan (European Commission, 2023). This action plan emphasises that grid investments alone are not sufficient, and that flexibility acquisition is indispensable. The European Commission therefore enforces the usage of new sources of flexibility by asking all Member States to ensure a “competitive, consumer-centred, flexible and non-discriminatory electricity market” is set-up (Electricity Market Directive (EMD) Art. 3) (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2019). In the Clean Energy Package (European Commission, 2019), the European Commission aims to empower consumers and other distribution-grid connected resources by facilitating the implementation of Demand Response mechanisms and their participation in electricity markets. Table 2-1 gives a non-exhaustive overview of the most important EU-regulation articles.

Table 2-1: EU regulation related to flexibility acquisition mechanisms.

Legilsation	Citation
Recitals 61 DIRECTIVE (EU) 2019/944	Distribution system operators have to cost-efficiently integrate new electricity generation, especially installations generating electricity from renewable sources, and new loads such as loads that result from heat pumps and electric vehicles. For that purpose, distribution system operators should be enabled, and provided with incentives, to use services from distributed energy resources (DERs) such as demand response and energy storage, **based on market procedures**, in order to efficiently operate their networks and to avoid costly network expansions.

	Member States should put in place appropriate measures such as national network codes and market rules and should provide incentives to distribution system operators through **network tariffs** which do not create obstacles to flexibility or to the improvement of energy efficiency in the grid.
Art. 17 (1-2) DIRECTIVE (EU) 2019/944	1. Member States shall allow and foster participation of demand response through aggregation. Member States shall allow final customers, including those offering demand response through aggregation, to participate alongside producers in a non-discriminatory manner in all electricity markets. 2. Member States shall ensure that transmission system operators and distribution system operators, when procuring ancillary services, treat market participants engaged in the aggregation of demand response in a non-discriminatory manner alongside producers on the basis of their technical capabilities.
Art 31 (2-5-6-7) DIRECTIVE (EU) 2019/944	2. In any event, the distribution system operator shall not discriminate between system users or classes of system users, particularly in favour of its related undertakings. 5. Each distribution system operator shall act as a neutral market facilitator in procuring the energy it uses to cover energy losses in its system in accordance with transparent, non-discriminatory and market-based procedures, where it has such a function. 6. Where a distribution system operator is responsible for the procurement of products and services necessary for the efficient, reliable and secure operation of the distribution system, rules adopted by the distribution system operator for that purpose shall be objective, transparent and non-discriminatory, and shall be developed in coordination with transmission system operators and other relevant market participants. The terms and conditions, including **rules and tariffs**, where applicable, for the provision of such products and services to distribution system operators shall be established in accordance with Article 59(7) in a non-discriminatory and cost-reflective way and shall be published. 7. In performing the tasks referred to in paragraph 6, the distribution system operator shall procure the non-frequency ancillary services needed for its system in accordance with transparent, non-discriminatory and market-based procedures, unless the regulatory authority has assessed that the market-based provision of non-frequency ancillary services is economically not efficient and has granted a derogation. The obligation to procure non-frequency ancillary services does not apply to fully integrated network components.
Art 32 (1) DIRECTIVE (EU) 2019/944	Member States shall provide the necessary regulatory framework to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas, in order to improve efficiencies in the operation and development of the distribution system. In particular, the regulatory framework shall ensure that distribution system operators are able to procure such services from providers of distributed generation, demand response or energy storage and shall promote the uptake of energy efficiency measures, where such services cost-effectively alleviate the need to upgrade or replace electricity capacity and support the efficient and secure operation of the distribution system. Distribution system operators shall procure such services in accordance with transparent, non-discriminatory and market-based procedures

	unless the regulatory authorities have established that the procurement of such services is not economically efficient or that such procurement would lead to severe market distortions or to higher congestion.
Art 40 (4-5) DIRECTIVE (EU) 2019/944	4. In performing the task referred to in point (i) of paragraph 1, transmission system operators shall procure balancing services subject to the following: (a) transparent, non-discriminatory and market-based procedures; (b) the participation of all qualified electricity undertakings and market participants, including market participants offering energy from renewable sources, market participants engaged in demand response, operators of energy storage facilities and market participants engaged in aggregation. For the purpose of point (b) of the first subparagraph, regulatory authorities and transmission system operators shall, in close cooperation with all market participants, establish technical requirements for participation in those markets, on the basis of the technical characteristics of those markets. 5. Paragraph 4 shall apply to the provision of non-frequency ancillary services by transmission system operators, unless the regulatory authority has assessed that the market-based provision of non-frequency ancillary services is economically not efficient and has granted a derogation. In particular, the regulatory framework shall ensure that transmission system operators are able to procure such services from providers of demand response or energy storage and shall promote the uptake of energy efficiency measures, where such services cost-effectively alleviate the need to upgrade or replace electricity capacity and support the efficient and secure operation of the transmission system.
Art. 1 (b) REGULATION (EU) 2019/943	This Regulation aims to: set fundamental principles for well-functioning, integrated electricity markets, which allow all resource providers and electricity customers non-discriminatory market access, empower consumers, ensure competitiveness on the global market as well as demand response, energy storage and energy efficiency, and facilitate aggregation of distributed demand and supply, and enable market and sectoral integration and market-based remuneration of electricity generated from renewable sources;
Art. 6 (1) REGULATION (EU) 2019/943	1. Balancing markets, including prequalification processes, shall be organised in such a way as to: (a) ensure effective non-discrimination between market participants taking account of the different technical needs of the electricity system and the different technical capabilities of generation sources, energy storage and demand response; (b) ensure that services are defined in a transparent and technologically neutral manner and are procured in a transparent, market-based manner; (c) ensure non-discriminatory access to all market participants, individually or through aggregation, including for electricity generated from variable renewable energy sources, demand response and energy storage; (d) respect the need to accommodate the increasing share of variable generation, increased demand responsiveness and the advent of new technologies.
Art. 16 (1) REGULATION (EU) 2019/943	Network congestion problems shall be addressed with non-discriminatory market-based solutions which give efficient economic signals to the market participants and transmission system operators involved. Network congestion problems shall be solved by means of non-transaction-based methods, namely methods that do

	not involve a selection between the contracts of individual market participants. When taking operational measures to ensure that its transmission system remains in the normal state, the transmission system operator shall take into account the effect of those measures on neighbouring control areas and coordinate such measures with other affected transmission system operators as provided for in Regulation (EU) 2015/1222.
Art. 34 (2) REGULATION (EU) 2019/943	Transmission system operators shall promote operational arrangements in order to ensure the optimum management of the network and shall promote the development of energy exchanges, the coordinated allocation of cross-border capacity through non-discriminatory market-based solutions, paying due attention to the specific merits of implicit auctions for short-term allocations, and the integration of balancing and reserve power mechanisms.

In response to the flexibility need challenges, and in response to EU regulation, system operators are now looking into non-technical solutions to gain access to flexibility. However, with some exceptions, the attention of system operators is mostly turned towards rule-based solutions and connection agreements, and tariff-based solutions. Only some system operators are already examining the option of market-based flexibility through local flexibility markets. This is, among others, due to the low maturity of these markets, but also because some EU regulation is still to be translated to national legislation. Furthermore, market-based solutions are only required when they are the most cost-efficient solution, which given the current immaturity of the market and the lack of market liquidity, is potentially not the case.

Given the low maturity of local flexibility markets, the ALEXANDER project focusses on solutions to unlock flexibility from lower voltage levels to its full potential. In D3.2, we zoomed in on the case where flexibility from distribution level resources is used to offer services to the TSO. In this deliverable, D3.3, we broaden the scope by also allowing the DSO to procure flexibility for its own grid needs. As a result, in D3.3, we consider the procurement of flexibility by both the DSO and the TSO. Flexibility procurement by the TSO alone has been discussed in D3.2. In what follows we discuss the current status of flexibility procurement by the DSO in Belgium.

2.2 Belgian TSO flexibility procurement mechanisms

As previously discussed in Alexander D3.2, historically, flexibility services were provided by transmission grid-connected resources, especially industrial demand response. However, growing challenges like aging infrastructure, distributed generation, and increased energy loads are pushing TSOs to diversify flexibility resources and include LV-connected assets. In Belgium, the TSO, Elia, manages four key flexibility products: Frequency Containment Reserve (FCR), Automatic Frequency Restoration Reserve (aFRR), Manual Frequency Restoration Reserve (mFRR), and the Capacity Remuneration Mechanism (CRM). While FCR, aFRR, and mFRR ensure frequency balance, CRM addresses capacity shortages caused by reduced nuclear generation.

Elia has been adapting regulatory and operational processes to allow distribution grid resources to participate in these transmission ancillary services. Furthermore, when FSPs at the distribution level wish to participate, additional processes for interaction between the DSO and FSP must be followed, as mandated by regulations. To address this, Synergrid, the federation of electricity and gas system operators in Belgium, introduced the “Synergrid Roadmap Flexibility” in January 2023, developed through working groups and public consultations, and presented it to Belgian energy regulators at the FORBEG forum. A public consultation followed in April 2023, and on June 30, 2023, Synergrid released three key documents for regulator review:

1. **Market Guide (MG FLEX)** (Synergrid, 2023)**:** This document standardizes the procedures of Belgian DSOs for all flexibility products, noting regional regulatory differences where relevant.
2. **Model Contract** (VREG, 2024)**:** Establishes a standard agreement framework between DSOs and FSPs.
3. **Technical Regulations (C8/01)** (Synergrid, 2021)**:** Outlines the qualification process for customer installations, including the Network Flexibility Study required for grid participation.

Synergrid submitted these documents on behalf of regional DSOs—Fluvius (Flanders), SIBELGA (Brussels), and ORES and RESA (Wallonia)—to the respective regional regulators. For more details, we refer to ALEXANDER D3.2 (Marques, et al., 2024).

2.3 Belgian DSO flexibility procurement

In D3.2 (Marques, et al., 2024), we explored the operation of TSO Flexibility Markets in Belgium. This chapter shifts focus to DSO Flexibility Markets, delving into the existing regulatory framework and ongoing discussions about its implementation.

2.3.1 Flanders

DSO flexibility mechanisms

Next to technical solutions, Fluvius, the DSO in this region, makes use of connection agreements and tariffs.

- **Connection agreements**: In the past, all Belgian regions made provisions to allow for alternative or flexible connection agreements, referred to as 'Aansluiting met Flexibele Toegang (AmFT)' in Flanders (Energy Decree Flanders, Article 4.1.18 and Technical regulations 'plaatselijk vervoersnet' Article III.2.4.5) , 'Accordement avec Accès Flexible' in Wallonia (Energy Decree Wallonia, Article 25 and 26) and 'Flexibel toegangscontract' in Brussels Capital Region (The technical regulations for regional electricity transmission networks in the Brussels Capital Region, Article 79 and Article 190). The variations in flexible connection agreements, as outlined in regional regulations, stemmed from differing modalities. However, in 2022, in the Technical Regulations for the Distribution of Electricity (TRDE) in Flanders, the regulation regarding AmFT is removed as it is not in line with the European framework (VREG, 2022). The reason for this can be found in Art. 32 of the fourth European electricity regulation, stating that the DSO needs to make a trade-off between the procurement of flexibility services and grid investments. In the old AmFT, this trade-off did not take place sufficiently. Furthermore, the old AmFT is only applicable for production installations while redispatching needs to be open for all production technologies energy storage facilities and demand response. Finally, there is no remuneration in the original AmFT. By the end of 2024, the Flemish Government should have implemented the most recent EMD (EUROPEAN PARLIAMENT AND COUNCIL, 2024) implying that by the end of 2025 the TRDE will be adapted. This will make room for a new scheme.
- **Grid tariffs**: Tariffs are set by the Flemish Regulator (VREG) and consists of a capacity tariff which is implemented since 2023. The tariff triggers an implicit response of distribution grid users to avoid local consumption peaks (VREG, 2022). In meantime, the DSO also performed a study on applying a ToU incentive on the capacity tariffs, however, there is no concrete draft on capacity based ToU tariffs yet (Fluvius, 2024).

Regulatory framework for local flexibility markets

Flanders transposed the EU-regulations, the Clean Energy Package (European Commission, 2019). Chapter V/1 contains all the provision related to flexibility and aggregation. This implies that, according to the Energy Decree (Vlaamse Codex, 2009), the DSO is expected to procure flexibility for local congestion primarily through a market-based approach (Art. 4.1.17/4 and 4.1.17/6). Only in exceptional circumstances (procurement of flexibility is not economically efficient, can lead to market distortions or can lead to more local congestion) it is allowed to make use of technical flexibility and/or by obliging grid users to participate. All details related to the procurement of flexibility services by the DSO are specified in subchapter III of chapter V/1. However, it is to be pointed out that the regulation in this subchapter is only in place until 31/12/2024.

In its technical regulations (TRDE) (VREG, 2023), the VREG mandates that DSOs define the rules for procuring market-based flexibility services (Articles 2.3.22-2.3.23). DSOs must outline the technical requirements, procurement process (e.g., tender or auction), remuneration, penalties, control mechanisms, and deviations from standard settlement or metering processes. Additionally, DSOs must determine how local flexibility services for congestion management or redispatching interact with other flexibility or supporting services (VREG, 2023, p. Art. 2.3.22 §2). The TRDE also requires a formal agreement between DSOs and FSPs, specifying key aspects to be addressed in the contract (VREG, 2023, p. Art. 2.3.21).

As specified in the Energy Decree (Vlaamse Codex, 2009, p. Art. 4.1.17/4), the DSO needs to set up a transparent and participative consultation to discuss with the TSO and all relevant market parties how the specifications should look like. The rules regarding how the consultation should take place are specified as well in the TRDE (VREG, 2023, pp. Art. 1.2.4, §5 and §7).

<u>Implementation of regulatory framework for local flexibility markets: Fluvius pilot</u>

According to the regulation, it is up to Fluvius (the Flemish DSO) to set up consultations to define the specific rules on flexibility procurement for local congestion management and the procurement of non-frequency related services for the DSO. In May 2022, Fluvius has set up consultations to define these rules (Fluvius, 2023). However, as the Flemish local flexibility market (LFM) field is at its infancy, both from the perspective of the FSP and from the perspective of the DSO, Fluvius has decided to start testing with LFMs. As such, they aim to learn by doing, adjusting their market specifications on the way.

Fluvius has started real LFM markets in Flanders for both reactive and active power (Fluvius, 2024). Participants will receive a remuneration for their delivered flexibility. Participants do need to have controllable assets, need to be located in a specific geographical area and they need to be registered as a DSO FSP. For the active power product, Fluvius defined three products: MaxUsage, ShortFlex and LongFlex. Fluvius requested NODES to manage the Flemish market platform (Fluvius, 2024).

2.3.2 Brussels Capital Region

<u>DSO flexibility mechanisms</u>

In its smart grid roadmap, Sibelga, the DSO in this region, touches upon all solutions available to manage its grid. The different options are illustrated in the pyramid in Figure 2-2. The first level is composed by the traditional grid dimensioning activities of the DSO. The second level includes all sorts of dynamic grid management, implying that management from a distance is possible so that less manual interventions are required. The third layer entails implicit flexibility, including tariffs or other incentives such as traffic lights that can encourage consumers to adapt a certain behaviour. With this mechanism, the DSO first puts in place adapted grid tariffs, to which traffic lights are added to provide additional incentives in case there are additional grid issues. In case the previous measures are not sufficient, the DSO can rely on local explicit flexibility which implies that the DSO makes use of specific connection agreements or a local flexibility market. Finally, in case all previous activities fail to offer all the required flexibility, the DSO can make use of regulatory constraint mechanisms such as curtailment to force the grid user to limit its consumption or injection. Right now, it is too early to decide which actions will receive priority, but the order in which they are presented in the pyramid is a good indication for the short run.

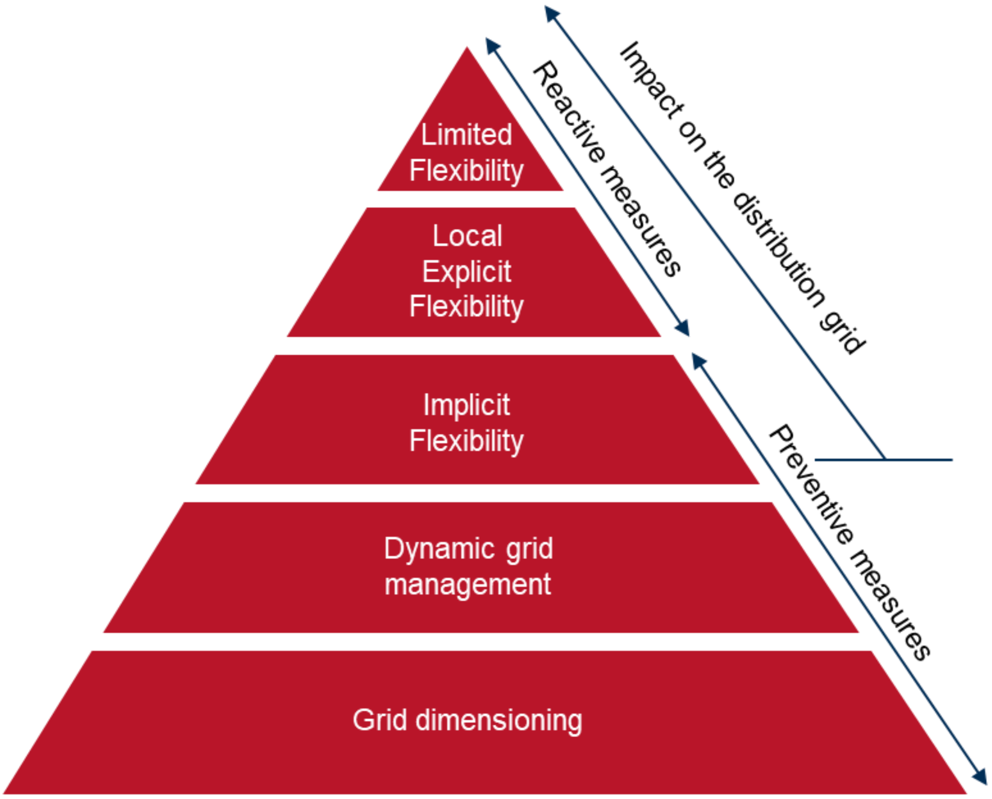


Figure 2-2: Pyramid of actions on the Sibelga Smart Grid. Source: (Sibelga, 2024).

- **Connection agreements**: A 'Flexibel toegangscontract' is allowed in Brussels Capital Region (Brugel, 2024). More specifically, it is specified that the DSO is allowed to set up specific connection rules depending on the local conditions on the grid. Both for assets that can control consumption and/or production of electricity are allowed to have flexible connection agreement. Such agreement is set up based on a template of BRUGEL, set up by Synergrid or the DSO (Brugel, 2024).
- **Rule-Based approach**: In Brussels, the DSO is allowed to limit the charging/discharging capacity of EVs (Art 2.30) (Sibelga, 2024). By January 2025 the latest, the minimum guaranteed charging capacity needs to be defined. This needs to be approved by BRUGEL. In addition, every 6 months, the DSO needs to share a list of access points that have been receiving limited capacity. Furthermore, by January 2026, the DSO needs to define all the technical criteria for limiting flexibility services (charging and discharging of EVs) (Art 2.31) (Sibelga, 2024).
- **Grid tariffs**: In Brussels, the distribution tariff is partly based on the technical capacity provided (kVA). Two tariff bands are foreseen, one tariff/kVA for grid connections below 13 kVA and one for grid connections above 13 kVA. The Brussels regulator foresees a progressive evolution of the share of the capacity tariff in the total grid fees. Between 2025 and 2027, the

percentages of the capacity component in the tariff are situated between 20-30%, which will increase up to 40% from 10/01/2028 onwards. The regulation foresees a more granular implementation of tariff blocks in future updates of the tariff methodology (Brugel, 2024). Today, for the volumetric part, only a distinction is made between peak (from 7-22h) and off-peak (from 22-7h and in weekends) periods. The purpose of defining the tariff in steps is to encourage the grid user to subscribe to the optimal power for his needs. Reductions in network tariffs are temporarily provided to energy communities as there is a believe that these can reduce the impact on the grid (Brugel, 2024). Sibelga, in its smart grid roadmap (Sibelga, 2024), also calls for attention for the simultaneity challenge that tariffs can bring along if they steer consumer behaviour at the same time in the same direction.

- **Traffic light**: Today, like other Belgian DSOs, Sibelga executes static NFSs (originally developed to offer LV-flexibility to the HV-grid). Sibelga is working towards a system where the traffic lights are determined in a more dynamic way, probably on a daily basis, without causing grid safety issues (Sibelga, 2024).
- **Limited flexibility**: In case of last resort, the DSO can intervene directly at the connection point of the client to avoid local congestions and to ensure safety and reliability of the grid. These actions can take place in all directions (both injection and consumption) (Sibelga, 2024). This is stipulated in the technical electricity regulation in art. 2.30 under §1 (Sibelga, 2023), which says that, under specific conditions:
    [1] the charging of an EV can be limited from its grid connection point;
    [2] the capacity to discharge an EV when he injects in the grid can be limited.

  Nevertheless, unless there are exceptional circumstances, the DSO does need to guarantee a minimal charging capacity which will be determine as of the 1st of January 2025 in a non-discriminatory way for a grid users. This minimum capacity needs to be approved by Brugel. By the 1st of January 2026, the DSO also needs to communicate the technical criteria for the limitation of flexibility services, linked to the charging and discharging of electric vehicles (Sibelga, 2023, p. Art 2.31).

Regulatory framework for local flexibility market

European Regulation 2019/944 (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2019) art 32 has been transposed in the Brussels Ordonnance of the 19th of July 2001 linked to the organisation of the Brussels Capital Region. The Ordonnance states in Art. 7 9° (Service Public Fédéral Justice, 2001) that the DSOs have a task to procure non-frequency related ancillary products and services that are necessary for the efficient, reliable, and safe operation of the distribution network, following transparent and non-discriminatory conditions and through a market-based approach, unless Brugel has determined that the purchase of these services cannot be carried out in a cost-effective manner. Art. 26bis (Service Public Fédéral Justice, 2001) indicates that any end customer has the right to offer flexibility services in a non-discriminatory manner in the electricity market.

Art. 7 is incorporated into the Brussels Technical Regulation for electricity grid management (Sibelga, 2023). Section 3.3, Art. 2.28 requires the DSO to establish specifications for the procurement of flexibility services via a market, with a transparent, participatory stakeholder consultation before January 1, 2026. Art. 2.29 mandates that if the DSO finds flexibility service procurement for local congestion management unfeasible or potentially market-distorting, it must prove this by January 1, 2025. If justified, Brugel may grant a 3-year derogation, renewable under the same conditions.

Implementation regulatory framework for local flexibility market

In the short run, Sibelga states in its smart grid roadmap (Sibelga, 2024) that it has concerns linked to commercial flexibility (e.g. local flexibility markets). A key concern raised by Sibelga is that in the Brussels Capital Region, it is likely that most of the congestion is cause by the charging of EVs. This is a challenge for the remuneration of the FSPs as these EV owners are the same actors that could resolve the congestion. This would lead to market distortions in the sense that the user of the distribution grid could cause congestion to being able to offer flexibility while being remunerated for it. This could lead to higher prices for commercial flexibility. A study by Deplasse (Deplasse & Associés, 2021) has also recommended not to provide compensations to FSPs in case they are also the actors responsible of causing the congestions.

In the short run, Sibelga is therefore not yet planning to opt for the implementation of a local flexibility market or commercial flexibility in general.

2.3.3 Walloon Region

DSO flexibility mechanisms

Next to technical solutions, Ores and RESA, which are the DSOs in this region, make use of connection agreements and tariffs.

- **Connection agreements**: All Belgian regions have made provisions to allow for alternative or flexible connection agreements, referred to as 'Accordement avec Accès Flexible' in Wallonia (Energy Decree Wallonia, Article 25 and 26 (The Walloon Parliament, 2022)). The decree of the Walloon Government defines a system for financial implementation. Some key provisions are the following: any new unit of more than 250 kW, or under certain conditions any capacity extension, must be flexible, i.e. it must be able to be modulated by the network manager to meet the operational security needs of the network in the event of congestion, provided that it is capable of injecting (see situation with non-return); any connection request which cannot be fully satisfied by the existing network or its planned developments is subject to a cost-benefit analysis with a view to assessing the relevance of making investments in the network; the producer candidate is allocated permanent and/or flexible capacity; the modulation of a permanent capacity opens the right, under certain conditions, to financial compensation for the loss of revenue linked to the modulation constraint imposed by the network manager. The unproduced volumes are estimated on the basis of the C8-04 prescription approved by the CWaPE (CWaPE, n.d.). In its articles 25decies, §3 and 26, §§2bis and 2 quinqies, the decree provides that the government is responsible for defining, on the proposal of the CWaPE (CWaPE, 2023) in consultation with the network managers and the stakeholders concerned, the methods of implementing the new connection regime with flexible access for production and storage units. Currently, Ores is launching a product on non-fixed connection agreements for new connections at medium voltage (MV). Regulation does not explicitly allow nor forbid this, so the DSO is still discussing with the regulator.

Note that according to the technical regulation (CWaPE, 2021), Art IV 41 states that the DSO has the right to set up contracts that allow in the limitation of load and/or injection to resolve congestion problems. The DSO needs to make a list of all these contracts and report it to the CWaPE.

- **Grid tariffs**: Walloon region will from 2026 onwards apply ToU tariffs with different colors (green, orange, red) where the price could be 5 times higher during peak moments. Currently, this is still a draft guideline (CWaPE, 2024). The regulators decision of the new methodology can be consulted here (CWaPE, 2023). While the tariff is a good starting point, it is to be noted that it is voluntary, implying that consumers can also still opt for the regular tariff. In addition, there is still compensation for PV, and consumers still receive a yearly invoice (which weakens the incentive message).
- **Flexible connection agreements and curtailment**: every generator above 150 kVA can be curtailed up to 5% of the yearly generation without being compensated. Originally, the

regulation in place focused on power, but it is going to change into energy. Ores is now looking into setting up a secondary market for the curtailed amount, ensuring that if the DSO wants to curtail, the generator can find another actor to consume the energy.

Regulatory framework Local Flexibility Markets

As specified in the Walloon electricity market regulation (Service Public Fédéral Justice, 2001), art. 11 states obligations of the distribution grid operator. This includes the adoption of objective, transparent, and non-discriminatory rules, based on the market. Network operators define, in consultation with the concerned network users and after approval of the CWaPE, the specifications for the flexibility services acquired and, where applicable, the standard products relating to these services in order to guarantee non-discriminatory access and the effective participation of all market players. The market procurement obligation does not apply where the CWaPE has assessed it as not economically efficient or where such procurement is likely to lead to serious market distortions or greater congestion.

Implementation regulatory framework

Ores is looking into setting up a local flexibility market for the MV-level. In the short run, they are planning to launch a procurement process for a market platform. The goal is to have a platform ready by the time that the uncompensated curtailment up to 5% of the generation is not sufficient anymore for the DSO.

2.3.4 TSO-DSO coordination for LV-flexibility market design in Belgium

This section pays attention to explicit flexibility mechanisms for distribution networks in Belgium, evaluating similarities and differences between the regions.

Today, as discussed in the Alexander report D3.2 (Marques, et al., 2024), everywhere in Belgium, an NFS is needed in case the TSO wants access to DSO-connected flexibility resources. On the other hand, DSOs in Belgium are not yet procuring flexibility through local flexibility markets. Only Fluvius is in a pilot phase, testing local flexibility market with both active and reactive products. Nevertheless, as presented in Section 2.3, DSOs are working out different flexibility acquisition mechanisms. While doing so, there is a lot of interaction between all system operators, organized through, for instance, Synergrid Workshops or bilateral meetings.

Despite this, TSO-DSO coordination remains an evolving area in the short term. For example, Fluvius's local flexibility market design document leaves room for clarification regarding the integration of flexibility services for local congestion management or redispatching with other flexibility or ancillary services. The document mentions that DSO services can be combined with others unless their activation creates conflicts. It assumes that the participation of these products will not exacerbate congestion issues. To strengthen the framework, VREG has recommended further specification on combining and prioritizing different flexibility services. This includes developing a transparent evaluation method to identify potential conflicts between services and outlining clear steps to address such conflicts if they arise (VREG, 2024). During the consultation, market parties such as Febeliec, FEBEG, and Bnewable emphasized the importance of providing clarity on these issues to ensure effective market participation and coordination.

Furthermore, VREG, the regulator in the Flanders region, along with other stakeholders such as Elia, FEBEG, Febeliec, Flux50, and ODE, highlights the need for stronger collaboration between the DSOs and TSO. To ensure the optimal use of flexibility and avoid a lock-in of resources, close cooperation between all system operators during flexibility procurement is essential. VREG recommends that

Fluvius establish robust data exchange processes between the DSO and TSO to support market activities related to flexibility. Additionally, it encourages Fluvius to develop a concrete plan and timeline for fostering effective collaboration among all system operators. VREG also references the iCAROS (Integrated Coordination of Assets for Redispatching and Operational Security) task force (Elia, 2018), which focuses on the Integrated Coordination of Assets for Redispatching and Operational Security, as a valuable initiative in this regard.

In conclusion, European legislation is prioritizing distribution-grid connected resources to provide flexibility, addressing the increasing need for flexibility due to the energy transition. While the TSO has historically procured flexibility, the growing electrification and renewable generation in distribution grids are increasing the flexibility needs of DSOs. However, a gap remains between regulatory requirements and practical implementation, with market-based flexibility acquisition by DSOs still rare, i.e., Fluvius is the only Belgian DSO actively establishing a local flexibility market. These aspects highlight the importance of TSO-DSO coordination, which we extensively discuss in the following chapters.

3 TSO-DSO coordinated flexibility acquisition

3.1 TSO-DSO coordination clusters

Chapters 1 and 2 demonstrate the importance of coordination among system operators when acquiring or procuring flexibility. This holds true regardless of whether the procurement is market-based or not. Effective coordination mechanisms are essential to ensure flexibility acquisition is conducted efficiently from a system-wide perspective.

In this chapter, we examine various approaches for system operators to coordinate their efforts. We analyse relevant methodologies and identify the most promising coordination schemes to be further evaluated in this deliverable. The design of potential TSO-DSO coordinated flexibility acquisition mechanisms depends on several key parameters, as illustrated in Figure 3-1.

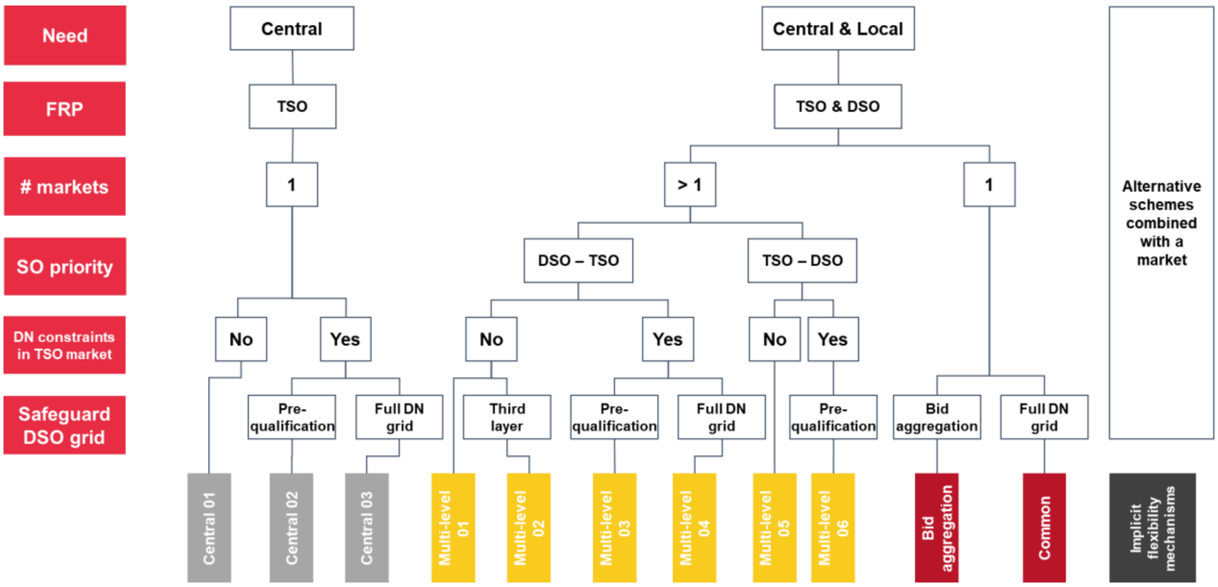


Figure 3-1: TSO-DSO coordinated flexibility acquisition mechanisms analysed in this deliverable.

These key parameters play a crucial role in determining the design, applicability, and effectiveness of flexibility procurement mechanisms. The first parameter is the **location of the flexibility need within the system**. This need can either be central, as in cases like balancing or congestion management at the transmission level, or a combination of central and local, the last includes, for instance, congestion management at the distribution level.

The second parameter is the **Flexibility Requesting Party (FRP)**, which identifies the primary party requesting flexibility. If the need is central, the TSO exclusively procures flexibility. However, if the need is both central and local, flexibility procurement is shared between the DSO and TSO.

The third parameter is the **number of markets** utilized for flexibility procurement. When the TSO is the sole procurer, a single market suffices to meet its needs. On the other hand, if both TSOs and DSOs procure flexibility, this can occur through separate markets (more than one) or a single joint market.

Another critical parameter is the **System Operator (SO) Priority**, which determines which operator (TSO or DSO) has precedence in accessing distributed flexibility. In separate markets, the question of priority becomes particularly important for distributed flexibility used by both TSOs and DSOs. For instance, if DSOs procure flexibility first, they can prioritize their local needs, with any remaining flexibility made available to the TSO. Conversely, if the TSO market occurs first, distributed resources are initially allocated to the TSO, leaving residual flexibility for the DSOs.

The **consideration of Distribution Network (DN) constraints in TSO markets** is another significant factor. When TSOs procure flexibility from distributed resources, the question arises as to whether distribution grid constraints are accounted for during the procurement process. If these constraints are not considered, activating distributed resources may result in violations within the DN, causing additional costs due to a lack of coordination. However, if DN constraints are considered, various methods can be applied to ensure compliance, as detailed in the following parameter.

Finally, the parameter of **safeguarding the DSO grid** focuses on the mechanisms used to maintain DSO grid constraints. As shown in Figure 3-2, the timing of when DN grid constraints are calculated and addressed plays a critical role. This can occur before procurement, using non-firm connection agreements (NFCA) or static prequalification; during procurement, through dynamic prequalification, bid aggregation techniques, or full network representation; or after procurement, via ex-post correction mechanisms.

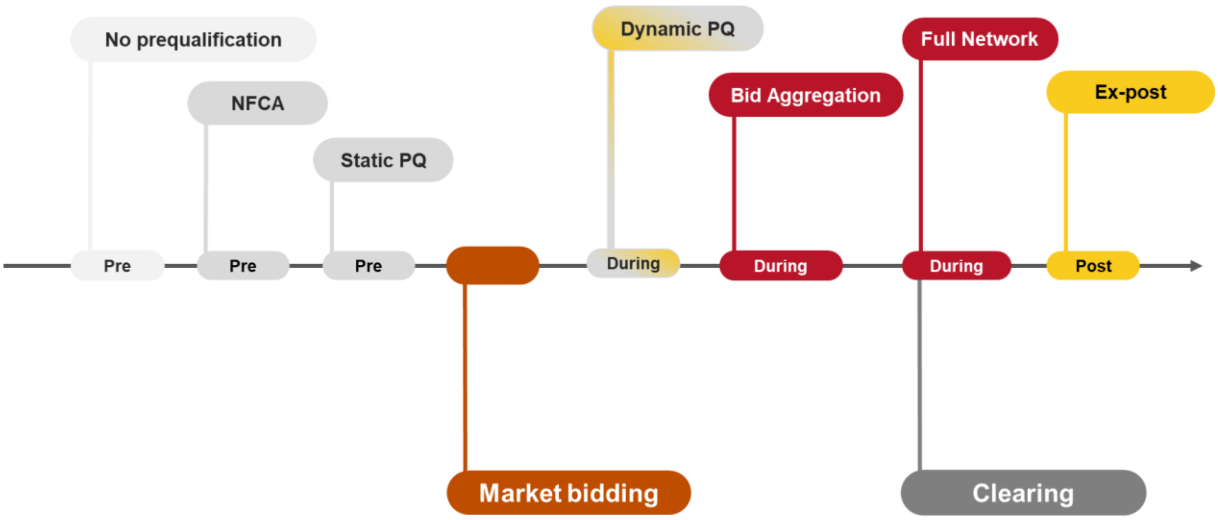


Figure 3-2: How the grid safety at system level is ensured when procuring flexibility

These parameters influence the design options for coordination and define the key characteristics of the mechanisms, such as applicable products and services, performance regarding procurement costs and grid safety, and the operational guidelines necessary for effective implementation (as shown in Figure 1-1). In this chapter, we explain the various TSO-DSO coordinated flexibility acquisition mechanisms illustrated in Figure 3-1. For clarity and ease of presentation, the numerous possible designs are categorized as shown in Figure 3-3. The first three clusters of coordination schemes focus on TSO-DSO market-based coordinated procurement, while the final cluster explores TSO-DSO alternative schemes combined with market-based procurement.

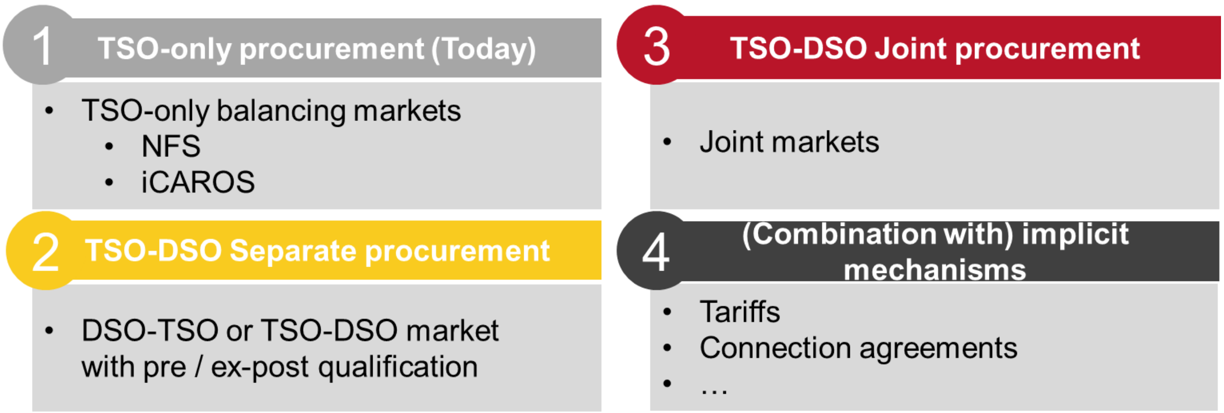


Figure 3-3: Groups of TSO-DSO coordination mechanisms.

3.2 TSO-only procurement (Today)

3.2.1 Explanation of the market models

In the first cluster, the TSO procures flexibility through a market (e.g., aFRR and mFRR products for balancing), with FSPs in the underlying distribution grids participating in this central market. The DSO does not directly procure flexibility, so coordination between TSO and DSO is critical to ensure that the TSO's procurement of distributed flexibility does not cause grid violations or issues within the distribution network, which would require DSO intervention. Given that this setup was extensively analysed in Alexander deliverable D3.2 (Marques, et al., 2024), this section provides a concise overview of its key aspects to support the later evaluation, in Chapters 0 and 6, of the model's benefits and limitations in terms of TSO-DSO coordination, as well as its applicability to the Belgian context.

As shown in Figure 3-2, the grid constraints of any system operator can be accounted for in different market stages, ranging from prequalification, procurement, activation, and settlement steps. In the specific case of central markets (left tree in Figure 3-1), distribution network constraints can be addressed in three ways: 1) not considered when the TSO procures flexibility from DERs (**central 01**); 2) considered during prequalification (e.g., static or dynamic), which determines whether DER resources can join the TSO flexibility market (**central 02**); or 3) incorporated into the procurement phase, along with the market clearing process for the TSO-level market (**central 03**). The three different designs' set-up can be visualized in Figure 3-4, and their blocks are explained below.

Figure 3-4: TSO-DSO coordination model when the TSO is the only one procuring flexibility (central market models).

TSO market procurement	Business-as-usual TSO market, which accounts for transmission-level constraints, but excludes distribution-level constraints. Bids from distributed-connected resources are allowed to participate.
DSO prequalification	Prequalification of distributed-connected resources to ensure grid compatibility before market participation. Methods include static approaches like Network Flexibility Studies (NFS) or dynamic techniques such as operating envelopes calculated for each market run.
TSO market procurement (with DN)	Modified TSO market in which DSO grid constraints are embedded in the procurement process (market clearing) to safeguard the distribution networks when procuring distributed-connected flexibility.

Following Alexander deliverable D3.2 (Marques, et al., 2024), the general conclusions for these models are as follows. If the **central 01** model is used, the TSO can achieve lower flexibility procurement costs but may cause grid violations within the distribution network, leading to challenges and costs for the DSO to implement corrective actions. On opposite side, if the **central 03** model is applied, distribution network constraints are embedded in the TSO's market clearing process, ensuring grid safety but increasing the TSO's procurement costs. The **central 02** model can produce better or worse results in terms of grid safety and procurement efficiency, depending on the prequalification method used (e.g., static Network Flexibility Study – NFS or dynamic operating envelope methods).

Given the lack of security and coordination inherent in the **central 01** model, especially with the increasing participation of distributed flexibility in the markets, and the challenges of implementing the **central 03** model—such as data sharing and defining the roles and responsibilities of the DSO—the **central 02** model is currently applied in Belgium and is the most relevant for this cluster.

Below we introduce two initiatives related to this TSO-DSO coordination design (**central 02**). The first is the Network Flexibility Study (NFS), implemented in Belgium as a static prequalification process managed by the DSO. This process evaluates distributed-connected resources to ensure they can provide flexibility without compromising grid stability. The second is the iCAROS project, led by the Belgian TSO, Elia. This initiative aims to enhance TSO-DSO coordination and enable the secure provision of flexibility services by distributed-connected resources, aligning with modern grid demands and European regulatory frameworks.

3.2.2 Network Flexibility Study (NFS)

An NFS (Network Flexibility Study) assesses whether flexibility activation could impact the distribution grid, such as causing congestion or stability issues. Based on the results, the DSO may limit or reject flexibility provision to maintain grid security. The NFS process, regulated by Synergrid C8-01 (VREG, 2024), determines whether grid users can offer flexibility, e.g., to TSO markets. Zones are categorized as green (no risks, flexibility allowed) or red (risk exists, flexibility restricted).

The process differs by region: in Flanders and Wallonia, grid users request the study, while in Brussels, only FSPs can do so (Synergrid, 2023). An NFS takes 30 days, but the DSO may reevaluate prequalified capacity in response to increased risks. In Flanders, LV-connected resources below specific thresholds (5 kVA for single-phase, 10 kVA for three-phase) are exempt from restrictions (VREG, 2023, p. Art. 2.3.26). Otherwise, LV resources must follow the NFS procedure.

If a new flexibility provider turns a zone from green to red, existing users remain qualified for 12 months. Prequalified capacity reductions also require a 12-month notice unless multi-year contracts apply. DSOs can impose temporary measures in emergencies (VREG, 2023, p. Art. 1.5.3), but congestion, per EU Regulation 2019/943 (European Commission, 2019), is not considered an emergency and must be managed through flexibility procurement under existing regulations. VREG highlights that DSOs must adhere to this framework to address congestion effectively (VREG, 2024).

3.2.3 iCaros

The iCAROS (Integrated Coordination of Assets for Redispatching and Operational Security) project, led by Elia, aims to enhance the coordination of grid assets for redispatching while ensuring operational security. The initiative aligns with European energy regulations, addressing the evolving needs of the power system as it integrates more distributed energy resources (DERs) (Elia, 2018).

A central focus of iCAROS is its new framework for outage planning, scheduling, and redispatching processes. The project establishes obligations for assets connected to the TSO grid and emphasizes the importance of coordination with DSOs to maintain grid stability and reliability. To support grid asset management, iCAROS introduces advanced methods for managing congestion and optimizing flexibility. It addresses both national and cross-border redispatching mechanisms, streamlining operational processes and improving efficiency (Elia, 2018).

Specifically for congestion and to create a more dynamic DSO-grid prequalification, the iCAROS project proposes DA computations which will allow Elia to inform the market on time regarding blocked assets in red flag calculated areas.

Stakeholder collaborations are a critical component of iCAROS. The task force works closely with producers, DSOs, regulators, and aggregators to ensure that the operational framework aligns with technical requirements and market needs. This engagement fosters transparency and enhances the practical implementation of iCAROS initiatives. The implementation of iCAROS is structured in phases to enable gradual adoption. Early phases focus on integrating existing processes, while future phases aim to refine redispatching methodologies and further enhance coordination between system operators and market participants (Elia, 2024).

3.3 TSO-DSO Separate procurement

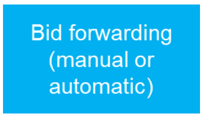
3.3.1 Explanation of the market models

In the second cluster, flexibility procurement is conducted not only by the TSO but also by the DSO, which establishes an LFM to address specific needs, such as congestion management. This dual procurement system allows DERs to be utilized for both local DSO requirements and central TSO needs. Separate markets can be organized for each system operator, with distinct procedures and rules governing aspects such as products and services, procurement processes, market clearing, and operational guidelines (see also Figure 1-1).

As illustrated in Figure 3-1, six potential designs are identified for this setup, all of which assume that distributed-connected resources can participate in both market types. These designs are detailed further in Figure 3-5, providing a comprehensive view of how DERs can be integrated into the flexibility markets of both TSOs and DSOs and showcasing TSO-DSO coordination aspects that need to be considered. After the figure, we provide a quick explanation of the additional blocks it contains.

Figure 3-5: TSO-DSO coordination model when both TSO and DSO procure flexibility in separate markets (multi-level market models).

LFM enabling the DSO procure flexibility for specific needs, such as congestion management or voltage control, with participation limited to distributed-connected bids addressing local requirements. As LFMs are relatively recent, the DSO must establish the framework, including defining products and services, market steps, market clearing mechanisms, and operational guidelines, to ensure smooth implementation and effective market functionality.



Transfer of uncleared bids from one market to the next market. It can occur manually, e.g., FSPs with non-selected bids actively participate in the subsequent market, or automatically, e.g., the market operator seamlessly transfers non-selected bids between markets. This process ensures that flexibility resources remain available for other market opportunities, improving market efficiency and resource utilization.

Post-qualification is a process conducted by the DSO after the market clearing to ensure that only grid-safe bids from distributed-connected resources are activated. Corrective procurement is an additional market stage run by the DSO in case the TSO procurement of DERs results in grid disturbances at the distribution level. This third DSO market addresses any operational issues caused by TSO activations, safeguarding grid stability and ensuring compliance with distribution-level constraints.

Following the explanations of the different blocks, we detail each of the multi-level designs of Figure 3-5. In the **multi-level 01** design, the DSO procures flexibility first to address its own needs, such as managing congestion in local grids. Any remaining flexibility bids are then forwarded to the TSO market, where DERs can be utilized without additional prequalification or consideration of distribution network (DN) constraints in the TSO market. This approach mirrors the drawbacks of the **central 01** model: while it can be advantageous in terms of lower procurement costs for the TSO, it fails to account for DSO grid constraints during TSO market operations. This omission poses significant risks to grid safety at the distribution level, potentially leading to operational issues that the DSO would then need to address.

In the **multi-level 02** design, the DSO also procures flexibility first, with any remaining bids forwarded to the TSO market. To address the distribution network safety issues inherent in the **multi-level 01** design, a third level is introduced. This additional layer enables the DSO to perform post-qualification, such as preventing the activation of certain distributed-connected resource bids selected by the TSO, or to procure corrective flexibility to resolve issues caused by TSO activations of distributed-located resources. A key challenge of this design lies in the timing. For example, the DSO must perform post-qualification or procure corrective flexibility after TSO markets, which often operate on very short timelines (e.g., 15 minutes before activation). Additionally, this design raises concerns about total procurement costs due to one level's actions potentially creating problems for the next. These issues are compounded by the lack of bid value stacking, particularly for distributed-connected resources, limiting their economic efficiency and effectiveness. These challenges will be analysed further in this document.

In the **multi-level 03** design, a prequalification step is introduced between the DSO and TSO markets. This step ensures that only bids from DERs that have passed the grid safety check are forwarded to the TSO market. By implementing this safeguard, the risk of TSO activations causing grid violations at the distribution level is mitigated. This approach enhances the coordination between the TSO and DSO, promoting both market efficiency and grid stability.

In the **multi-level 04** design, neither prequalification nor post-qualification/correction is implemented. Instead, the safety of the distribution network (DN) is assured by incorporating grid constraints directly into the TSO market clearing process. As in previous multi-level designs, the DSO runs its market first, and any uncleared bids are forwarded to the TSO market. The TSO market is then cleared, considering the distribution grid's constraints, much like the **central 03** market approach. This design introduces similar challenges to those seen in **central 03**, such as issues with data sharing and with the roles and responsibilities of the DSO. These challenges complicate the implementation of the model due to the need for close coordination between the two operators, especially regarding the exchange of operational data and decision-making authority.

The last two designs reverse the order of the system operators. In **multi-level 05**, the TSO procures flexibility first, and any uncleared bids from the distribution systems are forwarded to the DSOs' LFMs. In this model, no prequalification of distributed-connected bids is performed before the TSO market, which means TSO activations of these resources can lead to grid issues in the distribution networks. If insufficient bids remain for the DSO in the second market, it may struggle to resolve both its initial needs and those caused by the TSO's market actions. Liquidity becomes a critical factor in maintaining grid safety in this design, as the availability of flexibility bids directly impacts the DSO's ability to ensure system stability.

In contrast, **multi-level 06** introduces a prequalification step for distributed-connected resources before the TSO market, preventing TSO market activations from creating additional grid issues in the distribution networks. By ensuring that only grid-safe bids are allowed in the TSO market, this model mitigates risks and enhances the coordination between system operators, promoting greater operational security.

The discussed multi-level designs highlight the balance between market liquidity, system coordination, and grid safety, and demonstrate how different prequalification and market sequencing strategies can impact the effectiveness of flexibility procurement.

Below, we further explore bid forwarding methods, which play a crucial role in enhancing coordination between the DSO and TSO. We then introduce the LFM being implemented by the Flemish DSO, Fluvius, as an example of a multi-level 03 market (with static prequalification). We address the coordination challenges that arise between this new LFM, and the established balancing markets operated by the Belgian TSO, Elia. Finally, we illustrate international examples of how to move forward from here.

3.3.2 A note on bid forwarding

As previously discussed in this section, there are various ways to forward unused bids from one market level to another when TSO-DSO separate procurement is applied. Bid forwarding refers to the process of identifying unused bids in one market and transferring them to a subsequent market. This mechanism plays a crucial role in improving TSO-DSO coordination and enhancing bid value stacking, particularly for resources connected to distribution systems.

In recent years, bid forwarding has garnered increasing attention. The draft NCDR (EUDSO Entity and ENTSO-E) indicates in recitals 41 that it aims to facilitate value stacking, e.g., through proper coordination of different markets, for instance in the case of bid forwarding. More specifically, it defines the following rules:

Art 53.4	National terms and conditions for market design for local services developed pursuant to Art 48 shall describe whether and under which conditions bids can be combined and forwarded to other markets. Service providers may offer their services in another market either themselves or by means of an intermediary or a market operator that forwards the bids, given that the concerned service provider has given its consent. If combined and/or forwarded bids are allowed at least the following should be described in the national terms and conditions: (a) requirements for combining and/or forwarding bids to other markets; (b) how information on consent of combining and/or forwarding bid is processed; (c) how locational information is included; (d) measures to maintain transparency for transferred bids; (e) whether and under which conditions service providers are allowed to change pricing and volumes or to withdraw bids; (f) liabilities and responsibilities for all market participants when transferred bids cannot be fully activated; (g) how forwarded and/or combined bids are priced and how service providers are compensated; (h) measures to avoid that the same bid is selected twice in separate markets or by different systems operators; and (i) how forwarded and/or combined bids are handled with respect to validation of service provision.

For Belgium and other Member States, this implies that bid forwarding should be permitted, but the specific conditions for its implementation will be determined at the Member State level within the National Terms and Conditions. According to the draft NCDR, bid forwarding can be executed in three ways: by an FSP directly, by a market operator, or through an intermediary. Currently, in Belgium, DSO-level markets are still in the early stages of development, and automated bid forwarding has not yet been implemented. As a result, bid forwarding is currently only possible if performed directly by the FSP.

3.3.3 Practical examples

All over Europe, this cluster of coordination schemes is starting to pop up the most. In quite some cases, DSOs implement a commercial flexibility market platform to facilitate setting up their market.

For instance, the Piclo commercial platform is being implemented in many UK DSO LFMs like the market of UK Power Networks, SP Energy Networks, Electricity North West, Northern Powergrid, Scottish and Southern Electricity Networks, National Grid Electricity Distribution and NESO, but it is also used in Ireland (ESB Networks), Italy (e-distriuzione), Portugal (E-Redes) and even Austrialia and the US. The EPEX SPOT LocalFlex platform is being implemented in LFMs in the Netherlands (GOPACS), Germany (Enera), and the UK (UKPN). The NODES platform has many implementations in Sweden (Effecthandel Väst, Sthlmflex, JämtFlex), in Norway (NorFlex, EuroFlex, FlexLab, Glitre Nett Sor Market, Arva Market / Smart Senja Market) but also in Germany and the UK. Furthermore, more recently, the NODES platform is also being piloted in the Fluvius LFM as discussed previously. There are also other flexibility market platforms like Equigy, Electron and N-SIDE. On top of this, some LFMs are setting up their own platform like RomeFlex, WindNode, SWITCH, etc.

Most of these examples encompass single flexibility markets with DSO(s) only. This is also the case of the Flemish Fluvius market. Whenever these markets are being set up in total isolation of the other markets, we end up in the multi-level 01 scheme as discussed in Figure 3-5. When DSO markets are just being set-up, and DSOs are still immature, it is perfectly understandable that decisions are taken independently and without coordination with other SOs. However, this has the potential disadvantage that markets might not be aligned, making it very complex for FSPs to bid in multiple markets and/or to understand the total playing field. It might decrease the flexibility potential of FSPs, or it might discourage them from participating as the total market set-up is too complicated.

For the case of Fluvius, we aimed to visualize this is Figure 3-6. The Fluvius LFM starts at D 16:00h. However, all other markets (mFRR, aFRR, FCR, DA, ID) start at D 00:00h. This means that if an FSP wants to bid for a specific day (for instance the 15th of August) it should split its day in 2 when joining the LFM. That is, the first part of the day is D-1 00:00-15:59, while the second part of the day is D: 16:00-23:59. If the FSP wants to bid in the first part of the day, it should already bid in the D-1 market. If it wants to bid into the second part of the day, it can follow the regular times for the D market. This means that for the Long Flex Capacity product, the FSP would bid in D-8 for the first part of the day and in D-7 for the second part of the day. Whenever bids are not accepted, they can be forwarded to the TSO capacity markets for D (15/08). Figure 3-6 describes the process for the first part of the day.

What this illustrates, is that the different timings complicate the bidding process for FSPs. It is therefore essential that one moves towards more coordination between different system operators. In the UK, ena (energy networks association) sets a good example by setting up an Open Networks Programme to transform the way UK's current energy networks operate. The goal of the Programme is to increase participation and volume in LFM by ensuring energy networks become more coordinated and aligned. They have different focus areas, as illustrated in Figure 3-7. Among others, they have standardised flexibility products over all UK DSOs, and they have standardised prequalification processes and settlement rules. Furthermore, they also focus on data harmonization and data transparency. All these and other focus areas are discussed in more detail in Figure 3-7. As can be seen on the website of ena (ena, 2024), planning tables are available with the implementation status of all UK DSOs to illustrate where DSOs are today with the implementation of the standardized products, prequalification processes… Apart from discussions, they therefore also show clear targets to measure their achievements (ena, 2024).

While the UK is an excellent example of coordination between system operators, there are also other European examples. For instance, in Norway, in the Norflex project, uncleared bids from the DSO-markets are aggregated by the market operator to reach the minimum block size of 1 MW and then forwarded to the Statnett mFRR market.

Finally, as Figure 3-5 illustrates many variations of TSO-DSO coordination in this second cluster of coordination schemes, it is fair to say that there are still many more variations possible. DSOs and TSOs are free to adapt markets in a way that suits their challenges and needs. An example of this can be found in the EUniversal project in the Portuguese demo and in the Coordinet project in the Swedish demo. In both cases, the market has some sort of automated market clearing process for congestion management in which a market clearing engine generates bid selection recommendations for the DSO. The market clearing recommendation is then checked by the DSO before approving it, to accommodate any forecast changes that had taken place after the bid selection recommendation. As such, especially in the short-run, where DSO market maturity (and trust in markets) might still be low from time to time, it is observed that DSOs prefer to have a check-system in place to double check recommended bids.

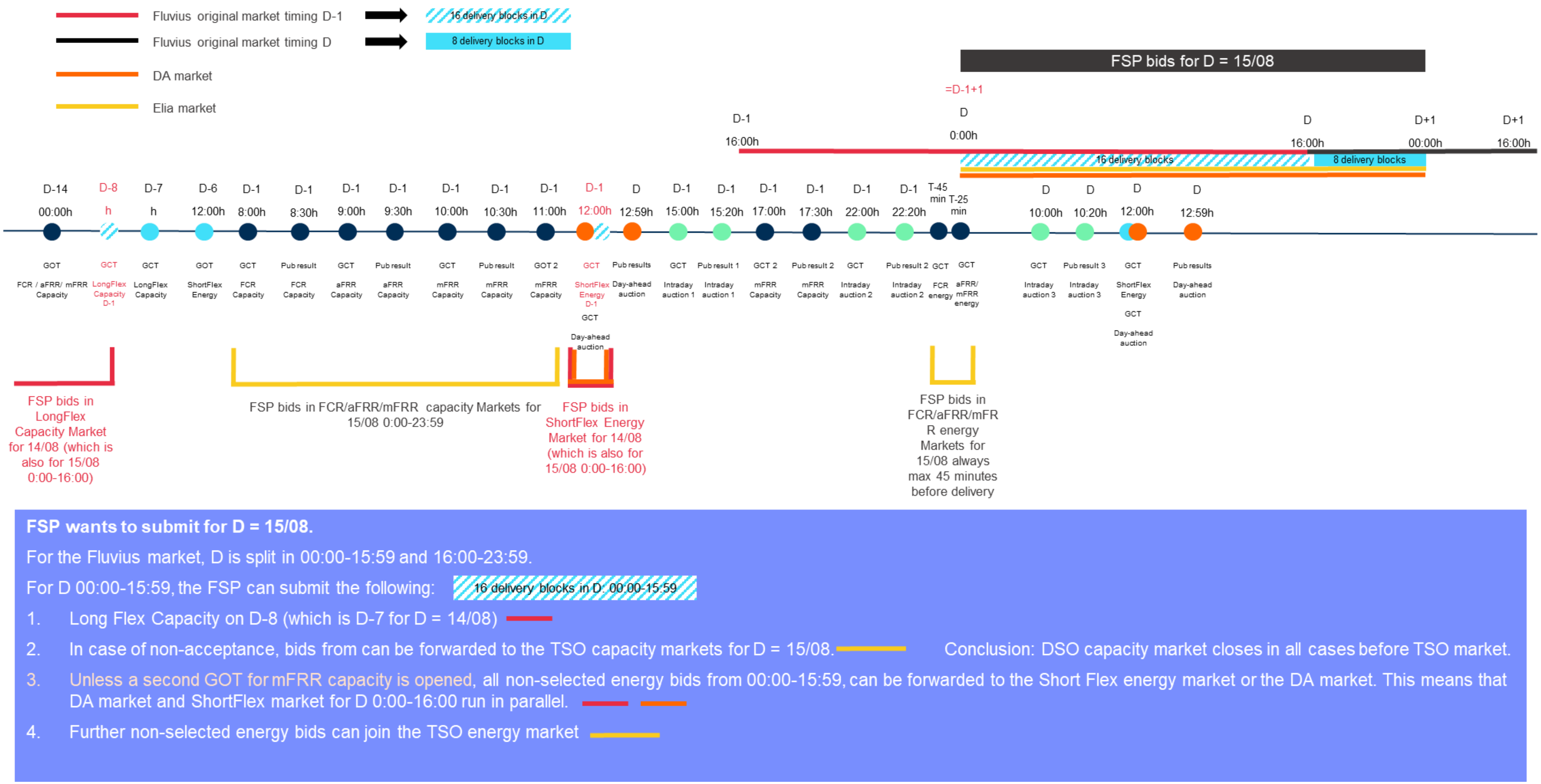


Figure 3-6: Timeline market timings Belgium compared to Fluvius LFM.

Focus area	Outcome	Definition of implementation	Impact for stakeholders
Making it easier for flexibility service providers to participate	**Standardisation of flexibility products**	80% of total volume of flexibility tendered by DNOs will be with common products having common technical specifications, excluding market testing flexibility products that have not been formally standardised under trial/ innovation projects	Flexibility providers are able to identify which services they're best placed to offer, based on a limited number of standardised DSO flexibility products.
	Standardisation of prequalification	All DNOs request standard data for technical and commercial pre- qualification for distribution flexibility services	Simplified and standardised pre- qualification process will ensure easy sign- up to DSO flexibility markets and a consistent user experience across the country.
	Standardisation of flexibility contracts	All DNOs use the same version of the standard agreement using common T&Cs and schedule headings for local flexibility tenders and specific ESO services (where applicable) for contracts awarded	Flexibility providers will have minimal legal costs in engaging with the market through standard agreements across all DSO and relevant ESO flexibility services, moving towards a framework arrangement.
	Standardisation of dispatch API	All DNOs adopt common API specification for dispatching flexibility	DSO flexibility market platforms will provide an optimal end- to- end experience, saving flexibility service providers from needing to develop multiple interfaces.
	Standardisation of settlement process	All DNOs use a common settlement approach for delivery of local flexibility services	Flexibility providers will have visibility of a transparent and consistent methodology by which payments are calculated following provision of local flexibility services.
Improving operational coordination between networks and companies	**Implementation of primacy rules**	All DNOs and ESO implement processes and information flows for increment 2 rules	Clear and consistent rules to manage conflicts arising within and across flexibility markets will help service providers improve their DSO flexibility offerings, whilst ensuring secure operation of the networks.
	Harmonisation of data shared between DNOs and ESO	Consistent bilateral operational data exchange between DNOs and ESO	Consistency of data sharing between DNOs and ESO ensures more robust forecasts and processes that will directly contribute to improving flexibility market operation.
	Harmonise DER visibility information	All DNOs use consistent Distributed Energy Resources (DER) visibility specifications and/or appropriate code mods are triggered	Requirements for new DER connections will be streamlined and network visibility will be improved through the consistent information flow from DER to DNOs.
Improving the transparency of processes and reporting	**Consistent Network Development Plans (NDP)**	All DNOs use consistent reporting format for Network Development Plans	Stakeholders are informed of major developments over a one to ten year time- frame with sufficient detail to aid their planning and forecasting activities.
	Consistent carbon reporting	All DNOs use a consistent format to report carbon impacts in the Distribution Flexibility Services Procurement Report, as part of SLC31E (this is a further refinement of the methodology implemented in 2023)	Customers will have visibility of local flexibility market carbon intensity across GB networks, reported through a consistent and transparent methodology.
	Sharing pre-SCR curtailment information	All DNOs provide consistent and accessible curtailment information for ANMenabled flexible connections pre- SCR (Significant Code Review)	Customers under flexible connections have accurate and consistent curtailment information allowing them to forecast their business plans and improve participation in flexibility markets.

Figure 3-7: ena areas of focus and impact.

3.4 TSO-DSO Joint procurement

3.4.1 Explanation of the market models

In the third cluster, both types of system operators (TSO and DSO) procure flexibility together using a joint market mechanism. This cluster includes two distinct designs which are shown in Figure 3-8. The additional blocks depicted in the figure are explained in detail below.

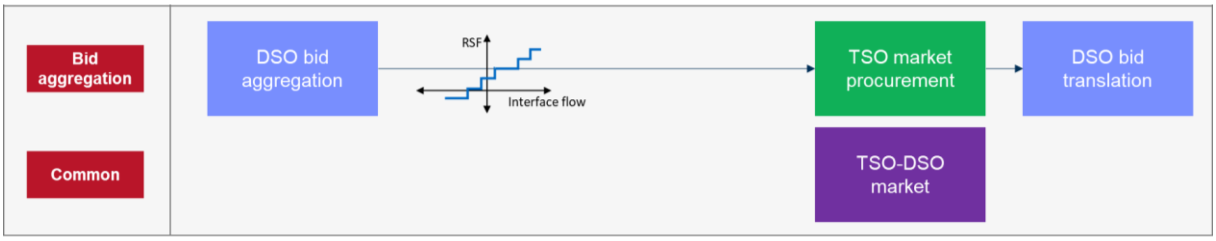


Figure 3-8: TSO-DSO coordination model when both TSO and DSO procure flexibility in joint markets (bid aggregation and common market models).

DSO aggregates bids connected at the distribution level to calculate a Residual Supply Function (RSF). This process considers the DSO's flexibility needs and network constraints to determine the amount of flexibility that can be made available for TSO procurement from the distribution grid, while ensuring the DSO can meet its own operational requirements.

DSO translates the RSF selected bid in the TSO-DSO market into the activation of local resources that are part of this selected bid. This ensures that the needs of both the TSO and DSO are effectively met.

Common market in which TSO and DSO procure flexibility jointly to meet their respective needs. All requirements, network constraints, and bids are considered jointly.

Building on the explanation of each block, we now describe the two TSO-DSO joint procurement designs mentioned earlier. In the **bid aggregation** model (SmartNet, 2019) (Sanjab, et al., 2023), each DSO first optimizes its flexibility procurement for a range of potential energy flows between the transmission and distribution networks. Using these results, the DSO constructs a residual supply function (RSF) that connects each energy flow option with its associated costs, ensuring that grid constraints are considered at each step. This simplified set of options is then passed to the TSO, showing the available flexibility and its cost. The TSO integrates this data with its own transmission-level bids and constraints to determine the optimal solution. After making its decision, the TSO informs each DSO, which then finalizes the selection of local resources to meet the agreed energy flow. Although the calculation of needs and network constraints is separate for the DSO and TSO, the use of the RSF in the TSO's market makes this process a joint procurement. Simulation results will show that this method can approach the performance of a fully integrated (common) market.

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showing the available flexibility and its cost. The TSO integrates this data with its own transmission-level bids and constraints to determine the optimal solution. After making its decision, the TSO informs each DSO, which then finalizes the selection of local resources to meet the agreed energy flow. Although the calculation of needs and network constraints is separate for the DSO and TSO, the use of the RSF in the TSO's market makes this process a joint procurement. Simulation results will show that this method can approach the performance of a fully integrated (common) market.

Finally, as previously explained, in the **common** market model the TSO and DSO procure flexibility jointly to meet their respective needs (e.g., for central balancing, congestion management across multiple voltage levels, etc.). This approach considers the requirements and network constraints of both systems, along with any interface limitations that may exist. Bids from all connected systems—spanning resources at high, medium, and low voltage levels—are pooled and cleared within the market. Below we present an international example of this market.

3.4.2 OneNet Northern Demonstrator

The Northern Demonstrator of the OneNet project implemented a common market model in which TSO and underlying DSOs come together in a joint market to procure flexibility, as illustrated in Figure 3-9. Multiple products and services were designed to address the (joint) needs of the different SOs. For instance, the NRT-P-E is an active product allowing both congestion management and balancing in near-real-time. Moreover, a unified flexibility register was established, providing a single interface for any FSP, regardless of location, to join the market, undergo prequalification, and offer flexibility. A joint optimization process was also developed, integrating the network constraints of both TSOs and DSOs as well as interconnection limitations.

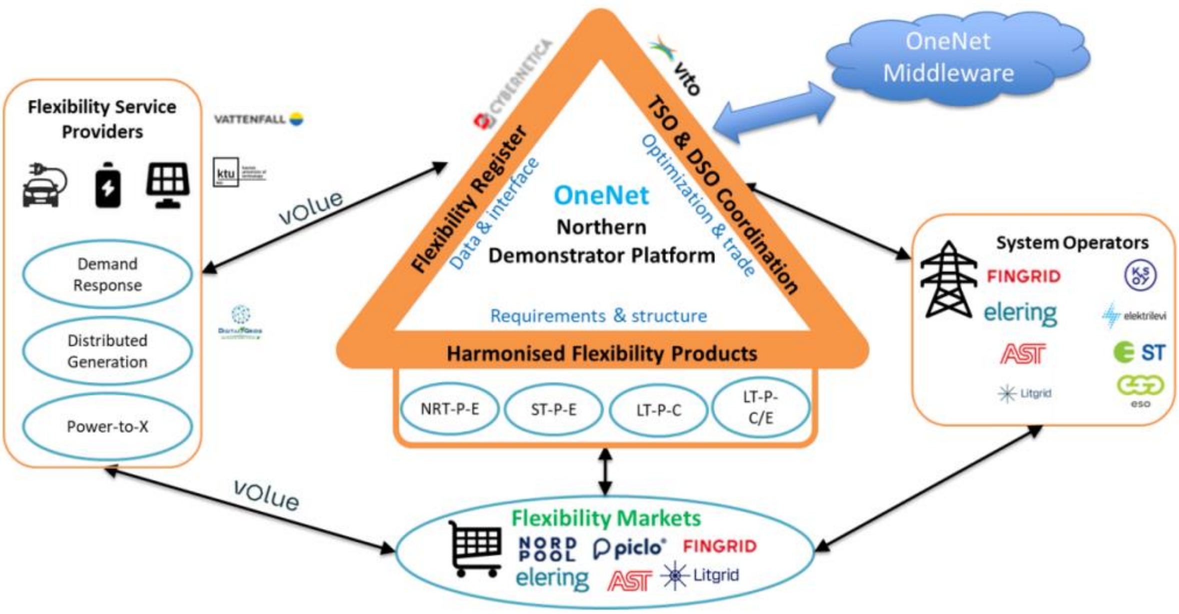


Figure 3-9: OneNet Northern Demo (Bashir , et al., 2024, p. 17)

This common market design was implemented and demonstrated in four countries (Estonia, Lithuania, Latvia, and Finland) yielding key insights into its efficiency and applicability. Joint procurement of flexibility significantly increased market liquidity and reduced overall costs for both DSOs and TSOs compared to separate markets. Accounting for the grid impact (PTDF[1]) of both systems was critical to minimizing costs and ensuring grid safety. Value stacking was observed, with flexibility bids addressing

[1] Power Transfer Distribution Factors.

both congestion and balancing needs. Finally, when DSOs resolved congestion locally, it sometimes negatively affected TSO operations, increasing overall costs and creating inefficiencies, demonstrating the advantage of the joint procurement.

3.5 Combination of explicit and implicit mechanisms

Apart from market-based flexibility provision mechanisms, system operators can also implement other implicit mechanisms, such as a connection agreement. In this section, we take a look at how connection agreements can have impact on the market-based mechanisms.

3.5.1 Non-firm connection agreements

Non-firm connection agreements (NFCAs) are connection contracts agreed between a system operator and an end-user that limit the end-users to export or import their full capacity (ACER, 2023), under specific conditions that will be described hereafter. Compared to other congestion management methods, NFCAs offer the advantage of not requiring DSOs to directly control behind-the-meter assets, which can be restricted by regulators in vertically integrated power systems. Additionally, NFCAs do not necessitate third-party, such as aggregators or FSPs, access to network data (Liu, Ochoa, Wong, & Theunissen, 2022).

NFCAs have been implemented for several years by DSOs, primarily at the medium and high voltage distribution levels, to regulate injections from renewable energy sources. At the low voltage (LV) level, this principle has recently been implemented for example in Australia through the EDGE project (Project EDGE, 2021), while in Europe currently under implementation in Germany, Hungary, Sweden, and Netherlands (ACER, 2023). For instance, the limit is set up to 5 kW in Australia (Liu, Ochoa, Wong, & Theunissen, 2022) and suggested to be 4.2 kW in Germany (Bundesnetzagentur, 2023). This means that when NFCA is activated by DSO, each end-user having contract is limited to produce or consume a maximum of 5 kW in Australia and 4.2 kW in Germany. The methodologies objectifying these guaranteed values are described in (Marques, et al., 2024), when defining the OE, the export and import limits.

Figure 3-10 illustrates the guaranteed capacity available at the end-user level. The light-yellow bars indicate the maximum connection capacity for both injection and offtake. This capacity is primarily determined by factors such as the number of connected phases (single-phase or three-phase), the network configuration (delta or star), the nominal voltage, and the connection's ampacity. These parameters are largely independent of the end-user's preferences or behaviour.

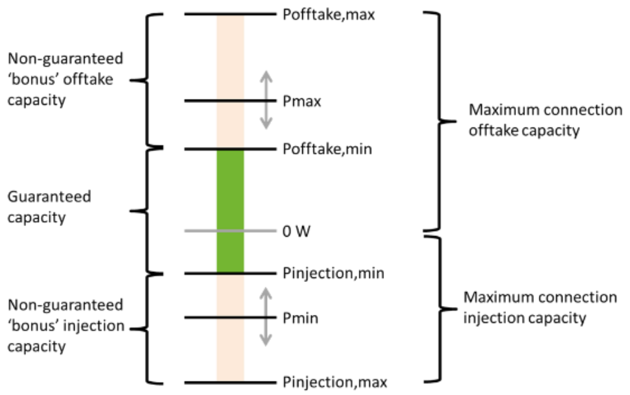


Figure 3-10: Representation of guaranteed capacity (green) compared to the maximum connection capacity.

The guaranteed capacity is represented in green on the figure. Under normal conditions, end-users can utilize anywhere from the minimum to the maximum of their connection capacity. However, when NFCAs are activated, their usage is restricted to the guaranteed capacity, as indicated by the green bar. NFCAs can have several characteristics:

- **Permanent or Temporary Activation**: NFCAs can either be activated permanently, effectively redefining connection capacity limits, or temporarily, under specific conditions such as a high risk of congestion. Temporary activation is more common, allowing end-users to utilize their maximum consumption or production capacities under normal conditions, with restrictions only during congestion risks. Some countries include provisions to reassure end-users, specifying the frequency and duration of activation (e.g., an NFCA may be activated up to ten times a year for a maximum of one hour each time).

- **Optimal or Fair Distribution**: NFCAs can apply uniform limits to all end-users or vary based on factors such as the power-to-connection-capacity ratio. DSOs are required to demonstrate non-discriminatory treatment of end-users to regulatory authorities. However, this principle of fairness can be implemented in various ways, which are formally evaluated in (Winkel, Lukszo, Neerincx, & Dobbe, 2024) for congestion management in distribution networks. For example, this principle is addressed in (Petrou, et al., 2020) and (Petrou, et al., 2021) by modifying the objective function to consider fairness.

- **Static or Dynamic**: The limits imposed by NFCAs can either be static, remaining constant regardless of time, or dynamic, changing based on temporal factors. Dynamic limits offer flexibility and can be tailored using various configurations, such as daily or seasonal time-of-use, 15-minute intervals, or even 1-minute intervals. The difference between static and dynamic power limits is illustrated in Figure 3-11.

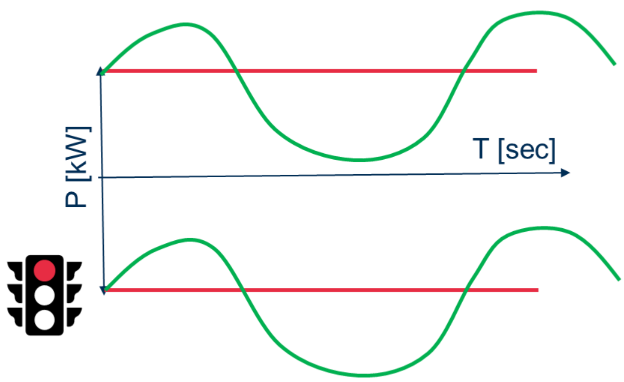


Figure 3-11: Static and dynamic limits of non-firm connection agreements.

Urban versus rural distribution grids

The DSO Observatory report (Meletiou, Vasiljevska, Prettico, & Vitiell, 2023) classifies distribution grids into four categories based on the area covered by the DSO, energy density, and number of customers. These characteristics, as defined in the report, are summarized in Table 3-1.

These categories are significant because congestion behaviour varies across them. NFCAs limits are expected to be mainly driven by ampacity limits in an urban distribution grid, while it is more expected to be voltage-driven in a medium or rural distribution grid.

Table 3-1: Classification of distribution grids based on the area covered by the DSO.

DSO category	Area $[km^2]$	Energy $[GWh/km^2]$	Customers $[10^6]$
Small	> 1000	≤ 10	≤ 1
Medium	> 1000	≤ 10	> 1 and ≤ 10
Urban	≤ 1000	> 10	-
Big	> 1000	-	> 10

NFCAs are implemented to ensure that LV distribution networks operate within voltage and current limits, safeguarding the reliability and safety of the LV distribution grid. When NFCAs are configured for temporary activation under conditions of high congestion risk, as described in *Alexander Deliverable 3.1* (Almasalma, Delchambre, D'hulst, & Vanthournout, 2022), they serve as a last resort measure for DSOs to prevent LV congestion.

However, while NFCAs aim to maintain network safety, they may inadvertently restrict the utilization of LV assets that have been pre-qualified and authorized to provide ancillary services in other markets. For example, consider an aggregator submitting a portfolio of LV assets, such as residential batteries or electric boilers, for a negative aFRR product between 16:00 and 20:00. If the portfolio is pre-qualified, accepted, and dispatched, the assets should be available for activation within this period. Now, imagine it's a high-demand day before a holiday, and several EVs are fast-charging in a specific LV feeder to prepare for travel. This leads to increased LV network stress, prompting the DSO to activate NFCAs to avoid congestion. Simultaneously, a European frequency incident occurs, requiring the TSO to call upon the full secondary reserve. Due to the active NFCA, the aggregator cannot dispatch the pre-qualified LV assets, limiting the available response capacity, potentially impacting grid stability during a critical event.

This scenario highlights the need to carefully balance network safety mechanisms like NFCAs with the operational flexibility required for integrating LV assets into broader energy markets in a TSO-DSO coordination scheme. In that specific case, as shown in Figure 3-12, it could be expected from the aggregator to redispatch the assets activation among its portfolio, from the TSO to redispatch to other aggregators or to use TSO market procurement mechanisms for correction.

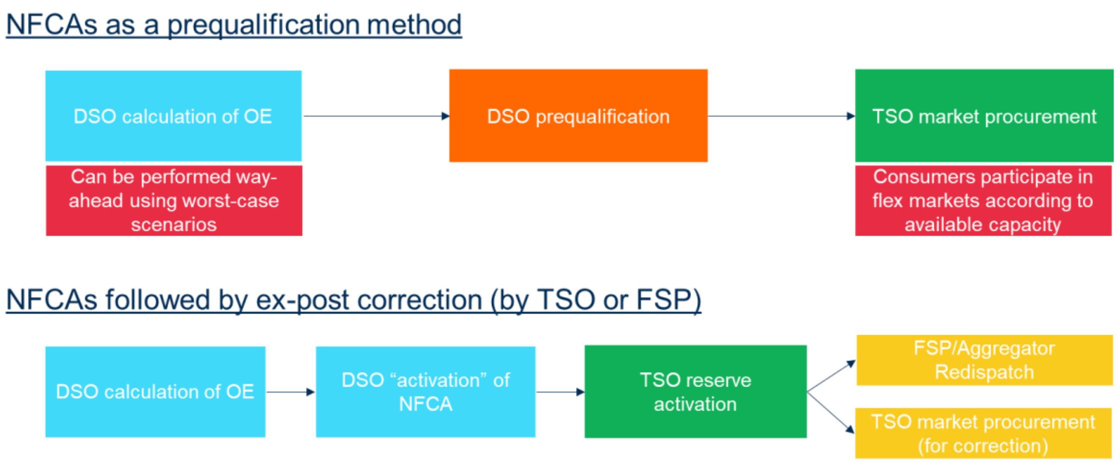


Figure 3-12: TSO-DSO coordination when implicit and explicit mechanisms are used together.

3.5.2 Practical example

The BiTraDER project (BiTraDER, 2022), led by Electricity Northwest, introduces a flexible trading platform that allows energy customers to trade curtailment positions. Non-firm connection customers can mitigate curtailment by trading with others, while firm connection customers generate revenue by selling unused capacity. This bilateral trading model boosts market liquidity, integrates renewables more effectively, and lowers system costs.

This initiative offers the potential for enhancing TSO-DSO coordination. By trading curtailment positions, customers having their NFCAs activated while also participating in TSO markets can trade their NFCA curtailment with other customers. This enables customers with NFCAs to participate in other markets while also unlocking flexibility from other customers, which maximizes system-wide efficiency.

The project involves phased development, from platform design to live network trials, ensuring effective implementation of near-real-time trades aligned with grid constraints. Figure 3-13 illustrates the principle behind the trading platform.

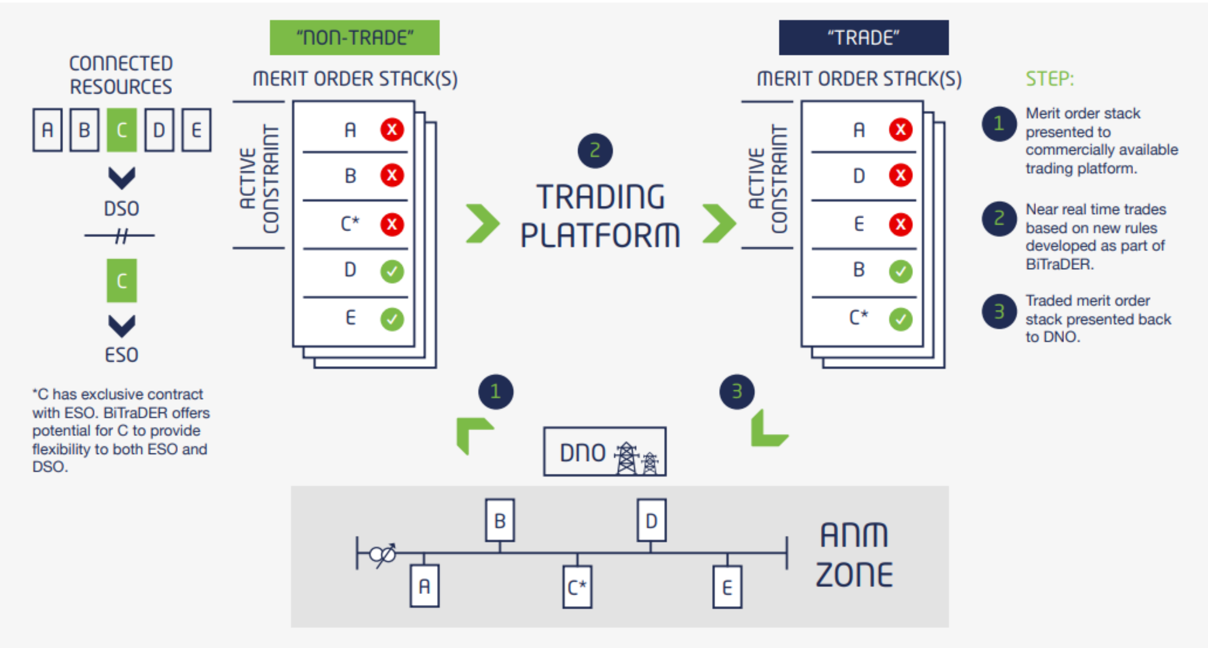


Figure 3-13: BiTraDER platform for trading non-firm connection agreement activations. Source: (BiTraDER, 2022).

4 Quantitative Analysis of TSO-DSO Coordinated Flexibility Market Schemes

In this chapter, the coordinated TSO-DSO flexibility market schemes introduced in Chapter 3 are quantitatively evaluated via a numerical simulation study.

4.1 Methodology

The quantitative analysis is performed using VITO's flexibility market simulator, which can be depicted in Figure 4-1. The different models of TSO-DSO coordinated market schemes are implemented in the market simulator. A set of market configuration parameters determines which market scheme is simulated for a given network and set of flexibility bids.

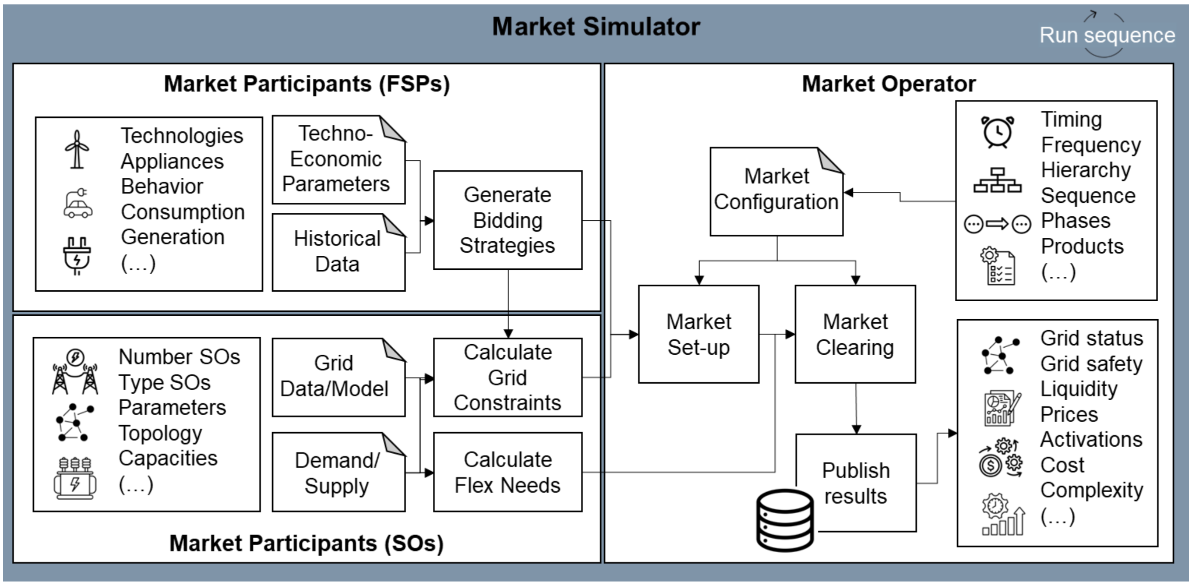


Figure 4-1 VITO's market simulator diagram

4.1.1 Mathematical Models of Coordinated Market Schemes

The coordinated market schemes analyzed and compared in this chapter are summarized in Table 4-1. We focus on coordination schemes in clusters 2 and 3 (Sections 3.3 and 3.4, respectively), which are only market-based schemes and where both the DSOs and TSO are procuring flexibility.

Table 4-1 Summary of coordinated market schemes

No	Market model name	Sequence	Cluster	Description
1	Multilevel 01	DSO-TSO	2	Vanilla DSO-TSO multilevel market model.
2	Multilevel 02	DSO-TSO	2	DSO-TSO multilevel market model with a corrective third-layer market (three-layer market).
3	Multilevel 03	DSO-TSO	2	DSO-TSO multilevel with a prequalification step in between DSO-layer and TSO-layer markets.
4	Multilevel 04	DSO-TSO	2	DSO-TSO multilevel market model which includes distribution grid constraints in the TSO-layer market.
5	Multilevel 05	TSO-DSO	2	Vanilla TSO-DSO multilevel market model.

6	Multilevel 06	TSO-DSO	2	TSO-DSO multilevel market model with a prequalification step before TSO-layer market.
7	Bid aggregation	N/A	3	Joint procurement via aggregation of distributed-level resources.
8	Common market	N/A	3	Joint procurement by including flexibility needs of all system operators and grid constraints of all networks.

All the coordinated market schemes in Table 4-1 are mathematically modeled using optimization-based models. Specifically, for the separate procurements (multi-level markets), the clearing problems of both the LFMs at the DSO level and the system-wide flexibility market at the TSO level as well as the corrective market in Multilevel 02 are formulated as a linear programming (LP) problem. While the common market is also an LP, the market clearing problem in the market scheme with bid aggregation is a mixed-integer LP, where the integer decision variables are introduced as a way to select exclusively one aggregated bid per distribution system. Furthermore, the aggregation step to obtain grid-safe aggregated bids involves solving multiple LPs. The prequalification method used in Multilevel 03 and Multilevel 06 is based on the operating envelope approach (Kaushal, Ananduta, Marques, Cuypers, & Sanjab, 2024), where optimal power flow problems are solved to calculate the operating limits of each flexibility resource. These models are used during the 'Market Clearing' process in the flowchart of Figure 4-1.

4.1.2 Network Models

For the transmission system, we consider the power transfer distribution factor (PTDF) model which relates the power injections at the transmission busses and the power flows on the lines. Furthermore, we include the line limit constraints. On the other hand, the distribution system constraints taken into account in the formulation include voltage limits and line limits. Furthermore, the power flow equations used to relate power flows and voltages are based on the linearized branch flow model (Sanjab, Mou, Virag, & Kessels, 2021). Therefore, these constraints are included in the LFMs of the DSOs. Similarly, in the prequalification steps and the bid aggregation step that require solving an optimal power flow problem, the same distribution system model and constraints are considered. We note that the model considered here is more complex than that in [Ananduta TEMPR 2024], which uses the PTDF model and only considers line limits. The network models are used in the 'Calculate Grid Constraints' process in the flowchart of Figure 4-1.

4.1.3 Key Performance Indicators (KPIs)

Four performance indicators are considered, as follows:

a. **Market inefficiency**. This metric measures how far the total procurement cost of a market scheme (J^{market}) is from the total procurement cost of the common market (J^{common}), which is the most efficient market. The market inefficiency, denoted by η, is defined by:

$$\eta = \frac{J^{\text{market}} - J^{\text{common}}}{|J^{\text{common}}|} \times 100\%.$$

b. **Grid safety**. Grid safety is measured by evaluating whether there exist network issues (line congestion or voltage violations) in the distribution networks after the cleared bids are activated. The network issues are measured by solving the linearized branch power flow equations given the activated flexibility resources and checking the satisfaction of all grid constraints mentioned in Section 4.1.2. Not only the number of grid constraint violations is recorded, but also the volume of violations.

c. **Computational time**. This metric measures the total time required to run the entire clearing process of a market scheme. This metric can be used to indicate the complexity of each market scheme.
d. **Unqualified flexibility volume**. This metric measures the total amount of flexibility resources that are unqualified. This metric is applicable only to market schemes that have a prequalification step.

The KPI calculation is done during the 'Publish results' process in the flowchart of Figure 4-1.

4.2 Description of Test Cases

To run one simulation instance, we must define the network used (as inputs in the SOs' blocks of Figure 4-1) and the set of flexibility bids (as inputs in the FSPs' block of Figure 4-1). All the test cases are generated based on the IEEE 14-bus transmission network interconnected with the MatPower 69-bus and 141-bus distribution networks. The base load and injection of each bus are modified to create balancing needs and some line limits of the distribution systems are adapted to create congestion. Then, in each bus of the transmission and distribution networks, flexibility resources are generated depending on the load and injection values. These resources will submit either upward or downward flexibility bids in the TSO-DSO coordinated markets.

To illustrate the performance of the different TSO-DSO We create four stylistic cases as follows:

- **Case A**. In this case, the overall demand is larger than the generation, thus the TSO has an upward flexibility need. The prices of the downward bids are between 10 and 25 €/MW. On the other hand, the prices of the upward bids are between 30 and 55 €/MW. The bids located in the distribution systems have higher prices than those in the transmission systems.
- **Case B**. The imbalance of this case is the same as that of Case A. Differently from Case A, the upward bids located in the transmission system are more expensive than those in the distribution systems. Specifically, the upward bids in the transmission system are priced between 90 and 165 €/MW, while the prices of the other bids follow the same rules as in Case A.
- **Case C**. The imbalance of this case is the same as that of Case A. In addition to the set of bids used in Case B, new upward and downward distribution-level bids are added. The prices of the new upward bids are more expensive than the upward bids in the transmission network while the new downward bids follow the rules in Case A. These new bids are introduced in critical nodes.
- **Case D**. In this case, the total generation is larger than the total demand so the TSO has a downward need. The bid price rules follow those in Case A.

4.3 Analysis of The Numerical Results

Let us now discuss our simulation results. The discussion is divided into the different KPIs previously mentioned.

4.3.1 Market inefficiency

Table 4-2 Market inefficiency [%]

Market scheme	Case A	Case B	Case C	Case D
Multilevel 01	3.09	-3.98	-4.54	157.20
Multilevel 02	3.09	22.82	23.99	157.20
Multilevel 03	3.09	29.70	20.18	157.20
Multilevel 04	3.09	10.17	0.00	157.20
Multilevel 05	-0.17	11.06	23.39	-53.54

Multilevel 06	-0.17	53.14	8.81	-53.54
Bid aggregation	0.31	1.42	1.17	27.27
Common market	0.00	0.00	0.00	0.00

The inefficiency of each market scheme is provided in Table 4-2. A positive value of inefficiency infers that a market scheme obtains a total procurement cost value larger than that of the common market, implying that market scheme loses its efficiency due to its design. As discussed in (Marques, Sanjab, Mou, Le Cadre, & Kessels, 2023), the common market is the most efficient market and the optimal cost of the multilevel market with full grid constraints (Multilevel 04) is lower bounded by that of the common market.

Interestingly, both in Cases A and D, all the DSO-TSO market schemes achieve optimal costs equal to that of Multilevel market with full grid constraints (Multilevel 04). This implies that, especially in these cases, prequalification and a corrective market layer do not affect the market efficiency of the multilevel scheme under the DSO-TSO sequence. On the other hand, as expected, the market scheme with bid aggregation performs better as its efficiency is close to that of the common market. Meanwhile, the TSO-DSO sequence market schemes have negative inefficiency, implying that their optimal procurement costs are lower than that of the common market. This is theoretically impossible and already indicates that in Cases A and D, these market schemes obtain cleared bids that cause grid constraint violations.

In Cases B and C, the baseline multilevel market scheme (multilevel 01), which does not include any measure to prevent unsafe use of distributed flexibility, has negative inefficiency, indicating grid constraint violations. On the other hand, the other market schemes have varying positive inefficiencies. Among them, again bid aggregation is the best-performing scheme as its inefficiencies are relatively very low. It has the lowest inefficiency in Case B, while in Case C, it is only bettered by Multilevel 04, which performs as well as the common market. The other market schemes perform comparably well as their inefficiencies are in the same order of magnitude. It is worth noting that, in particular for Case B, as will be discussed next, Multilevel 02 and Multilevel 05 have grid constraint violations despite positive inefficiency, implying that not only they can be costly but also not safe.

4.3.2 Grid Safety

The grid safety KPI results are presented in Table 4-3 until Table 4-6.

Table 4-3 Number of congestions

Market scheme	Case A	Case B	Case C	Case D
Multilevel 01	0	40	24	0
Multilevel 02	0	18	0	0
Multilevel 03	0	0	0	0
Multilevel 04	0	0	0	0
Multilevel 05	12	17	0	12
Multilevel 06	12	0	0	12
Bid aggregation	0	0	0	0
Common market	0	0	0	0

Table 4-4 Maximum volume of congestion (in proportion to the line limits) [%]

Market scheme	Case A	Case B	Case C	Case D
Multilevel 01	0	167.40	147.4	0
Multilevel 02	0	265.73	0	0

Multilevel 03	0	0	0	0
Multilevel 04	0	0	0	0
Multilevel 05	173.4	110.13	0	173.4
Multilevel 06	173.4	0	0	173.4
Bid aggregation	0	0	0	0
Common market	0	0	0	0

Table 4-5 Number of voltage violations

Market scheme	Case A	Case B	Case C	Case D
Multilevel 01	0	10	9	0
Multilevel 02	0	35	0	0
Multilevel 03	0	0	0	0
Multilevel 04	0	0	0	0
Multilevel 05	0	21	0	0
Multilevel 06	0	0	0	0
Bid aggregation	0	0	0	0
Common market	0	0	0	0

Table 4-6 Maximum volume of voltage violation (in proportion to the voltage limits) [%]

Market scheme	Case A	Case B	Case C	Case D
Multilevel 01	0	21.19	17.10	0
Multilevel 02	0	31.80	0	0
Multilevel 03	0	0	0	0
Multilevel 04	0	0	0	0
Multilevel 05	0	18.34	0	0
Multilevel 06	0	0	0	0
Bid aggregation	0	0	0	0
Common market	0	0	0	0

Table 4-3 and Table 4-4, respectively, provide the number and the maximum volume of line congestions while Table 4-5 and Table 4-6, respectively, show the number and the maximum volume of voltage violations. As previously mentioned, in Cases A and D, the outcomes of the multilevel market schemes with TSO-DSO sequence (Multilevel 05 and Multilevel 06) create some network issues, which are line limit violations. We can infer that the DSO markets that come after the TSO market do not have enough flexibility bids to resolve the network issues, already existing before the market with the addition of the clearing of the TSO market. Even with a prequalification step before clearing the TSO market (Multilevel 06), this issue persists, and it shows an example that having a prequalification in the TSO-DSO market sequence is not enough to ensure grid safety. The main issue in these two cases is that when the interface flow is fixed by the TSO market, the DSO markets must rely on local flexibility resources not only to satisfy the interface flow value set by the TSO market outcome but also to resolve their flexibility needs. Differently, all the multilevel market schemes with DSO-TSO sequence produce outcomes that do not create any line congestions in Cases A and D.

However, in Case B, Multilevel 01 and Multilevel 02, which are DSO-TSO-sequenced schemes also have line congestions and voltage violations. The result of Multilevel 01 in this case shows an example that local issues are generated by the activation of distributed flexibility by the TSO market. Meanwhile, the result of Multilevel 02 in Case B shows that a corrective market cannot always resolve these local issues. On the other hand, the result of Multilevel 03 (DSO-TSO market with OE-based prequalification), not only in Case B but also in Case C, shows that the prequalification step can successfully prevent the TSO market from causing local issues. Furthermore, the advantage of having a prequalification step before the TSO market can also be seen for the TSO-DSO market sequence in Case B, as Multilevel 06 (with prequalification) does not have any network issues as compared to Multilevel 05 (without prequalification), which has some voltage violations and line limit violations.

Finally, in all the cases, since Multilevel 04 and the common market include directly distribution grid constraints whenever distributed flexibility resources participate, no network issues are observed. Furthermore, the market scheme with bid aggregation also does not produce any network issues. This is achieved by the bid aggregation process that ensures that only aggregated bid values that correspond to a safe operation of the distribution grid are taken into account in the clearing process.

4.3.3 Computational time

To evaluate the computational complexity of each market scheme, the computational time needed to perform all the market clearing steps is measured, as shown in Figure 4-2. Since any of the market clearing problems (i.e., each market in a multilevel scheme and the common market) are an LP, the computational time of solving one market problem to another is quite similar, i.e., around 1.5-2 seconds. The multilevel market schemes have a larger computational time than the common market since the DSO markets are solved sequentially. Furthermore, the prequalification steps for Multilevel 03 and Multilevel 06 require solving two OPF problems for each distribution network, which are also LPs. On this KPI, the market model with bid aggregation performs the worst and in fact, its computational time is more than 4 times as much as the multilevel market schemes with prequalification (Multilevel 03 and Multilevel 06) and almost 10 times as much as the other multilevel market schemes. This is due to the bid aggregation process and the market clearing problem, which is a mixed-integer problem as opposed to an LP. In the bid aggregation process, multiple OPF problems, which are LPs, must be solved. As discussed in (Ananduta, Sanjab, & Marques, 2024), the computational time of this market scheme depends on the aggregation step size chosen, i.e., the smaller the aggregation step size, the larger the computational time is.

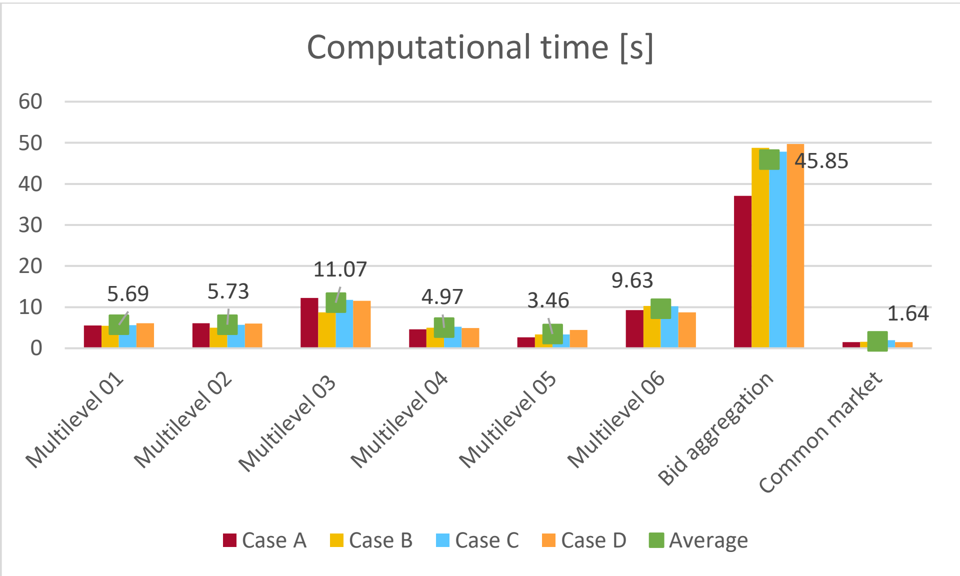


Figure 4-2: Recorded computational time (seconds).

4.3.4 Unqualified flexibility of the market schemes with prequalification

Let us now take a closer look at the prequalification method used to ensure grid-safe activation of distribution-level flexibility resources. As seen in Table 4-3 until Table 4-6, the DSO-TSO multilevel market with prequalification always produces market outcomes that are grid-safe. However, as seen in Table 4-2, it can have higher inefficiency as compared to the idealized Multilevel 04, which has the same multilevel market structure but includes directly the distribution grid constraints. The loss in efficiency is indeed due to the prequalification step, which limits some distributed flexibility due to grid safety concerns. The prequalification step in Multilevel 06 is slightly different although it is still based on the operating envelope method as in Multilevel 03. Since, in Multilevel 06, the TSO-level market is cleared before the DSO-level markets, the distribution grids might still have some network issues. In this case, the prequalification process must be adjusted such that the limits imposed ensure that the clearing of distributed bids in the TSO-level market does not cause any additional network issues. Unfortunately, as seen in Table 4-3 and Table 4-5, for Cases A and D, the Multilevel 06 is not grid-safe, as previously discussed. Nevertheless, Table 4-7 shows the quantity of flexibility unqualified by the prequalification step, not only in Multilevel 03 but also Multilevel 06. Note that the unqualified volume is in proportion to the available distributed flexibility that can be forwarded to the TSO-level market. While in Multilevel 06, the available flexibility equals the original total quantity, in Multilevel 03, it amounts to the total remaining flexibility after clearing the DSO-level markets.

Table 4-7 Total unqualified volume (normalized) of distributed flexibility resources for TSO-level markets

Market scheme	Case A		Case B		Case C		Case D	
	Up	Down	Up	Down	Up	Down	Up	Down
Multilevel 03	79.4%	100%	75.6%	100%	95.0%	71.7%	79.4%	100%
Multilevel 06	67.3%	98.0%	100%	98.0%	96.4%	98.2%	67.3%	98.0%

4.3.5 Comparison of prequalification methods

In the above results shown in Table 4-3 until Table 4-6, we use a prequalification step that is based on the operating envelope method (Kaushal, Ananduta, Marques, Cuypers, & Sanjab, 2024). Specifically, during the operating envelope calculation, the bid prices are taken into account to ensure alignment with the market clearing problem. In (Kaushal, Ananduta, Marques, Cuypers, & Sanjab, 2024), this choice is called price-based OE, while a uniform OE, where each bid is equally weighted in the OE calculation, is also tested. We have also tested another prequalification method initially proposed in the Interrface project (H2020 INTERRFACE, 2022) where some bids are fully disqualified to ensure the entire set of forwarded bids are grid-safe. The qualification process is iterative where at each iteration, the most expensive bid is disqualified until the remaining bids are grid-safe if they are fully activated (Ananduta, Sanjab, & Marques, 2024). Our simulation results, as summarized in Table 4-8, shows that the price-based OE is indeed the best prequalification method option among them as it has the lowest market inefficiency and highest liquidity. Furthermore, the Interrface prequalification method requires significantly higher computational times than the OE-based method and they are even higher than those of the bid aggregation methods.

Table 4-8 Performance of OE-based and Interrface prequalification methods

Market scheme		Price-based OE	Uniform OE	Interrface
Market inefficiency	Case A	3.09%	3.09%	3.09%
	Case B	29.7%	66.8%	41.8%
	Case C	20.2%	38.6%	41.4%
	Case D	157.20%	157.20%	157.20%

Number of grid violations	Case A	0	0	0
	Case B	0	0	0
	Case C	0	0	0
	Case D	0	0	0
Computational time	Case A	12.25 s	12.11 s	512.80 s
	Case B	8.71 s	9.82 s	475.43 s
	Case C	11.74 s	11.72 s	551.17 s
	Case D	11.56 s	11.90 s	534.39 s
Unqualified Upward	Case A	79.4%	79.4%	88.6%
	Case B	75.6%	75.6%	91.7%
	Case C	95.0%	73.4%	89.9%
	Case D	79.4%	79.4%	88.6%
Unqualified Downward	Case A	100%	100%	100%
	Case B	100%	100%	100%
	Case C	71.7%	100%	100%
	Case D	100%	100%	100%

4.3.6 Overall analysis

From our numerical simulations, we can observe that for multilevel market schemes, the DSO-TSO sequence performs better than the TSO-DSO sequence in terms of market efficiency and grid safety. Comparing these schemes without any bid forwarding measure, Multilevel 01 provides grid-safe outcomes in Cases A and D while Multilevel 05 only provides a grid-safe outcome in Case C. It is worth mentioning that, in Case B, Multilevel 05 loses efficiency but the cleared bids are still not grid-safe. When prequalification is put in place before the TSO-level market, the results are even more conclusive as the DSO-TSO market sequence (Multilevel 03) can always provide grid-safe outcomes while this is not necessarily the case for the TSO-DSO sequence (Multilevel 06), e.g., Cases A and B (Table 4-3). In terms of market inefficiency, when both markets provide grid-safe outcomes, there is no conclusive evidence of which one performs better. In Case B, Multilevel 03 has a market inefficiency of 11.06% as compared to 53.14% for Multilevel 06, while in Case C, Multilevel 03 has a market inefficiency of 23.39% as compared to 8.81% for Multilevel 06. We note that both market sequences have practically the same computational complexity.

In terms of grid-safe bid forwarding methods put in place, the preventive method, i.e., prequalification, outperforms the corrective method, as we can compare the performance of Multilevel 03 and Multilevel 02. Particularly, the corrective method (Multilevel 02) cannot always provide grid-safe outcomes (e.g., Case B) and, when it does, its market inefficiency is not lower than Multilevel 03 (e.g., Case C). However, in terms of computational complexity, the corrective method is better than the preventive method as can be seen from their computational times.

Finally, the bid aggregation method outperforms the DSO-TSO multilevel market with prequalification in terms of market efficiency while always ensuring grid-safe outcomes. However, the efficiency performance of this method relies heavily on the bid aggregation step size. As shown in (Ananduta, Sanjab, & Marques, 2024), the smaller the step size is, the closer the efficiency of this market scheme to that of the common market, however at the cost of computational complexity, which can increase exponentially.

4.4 Supporting Publication

Some theoretical and numerical analyses of Multilevel 02 (DSO-TSO multi-level market with a third corrective market layer), Multilevel 03 (DSO-TSO multi-level market with a prequalification step), and the market scheme with bid aggregation are presented in the following paper, which is under review at the time of the publication of this deliverable:

- W. Ananduta, A. Sanjab, and L. Marques. "Ensuring Grid-Safe Forwarding of Distributed Flexibility in Sequential DSO-TSO Markets", available online at https://arxiv.org/abs/2406.04889.

5 Quantitative analysis of non-firm connection agreements

This chapter provides a quantitative analysis of NFCAs, discussed in Section 3.5.1, that is applied to two types of LV distribution grids: a simple benchmark grid and 49 real LV feeders from Sibelga in Brussels. The benchmark grid serves to illustrate qualitative concepts discussed earlier in the report, offering clear and simplified examples. The analysis of the Sibelga grids demonstrates the scalability of the proposed methods and enables discussions on the unique characteristics of urban LV distribution networks.

It is important to note that this chapter focuses solely on the results of NFCAs. The development of simulations and studies analysing the impact of NFCA activations on the availability of LV resources to provide flexibility to markets, such as TSO-level markets, is left for future work. Nevertheless, the aspects related to TSO-DSO coordination of implicit and explicit mechanisms discussed in Section 3.5 remain applicable.

5.1 Case study A – Benchmark grid

The reduced IEEE European LV test feeder is chosen for the first case study. This grid is represented in Figure 5-1 with 55 end-users and their initial phase connections. Each end-user is connected to the grid with a maximum power capacity (in this case: ± 9.2kVA).

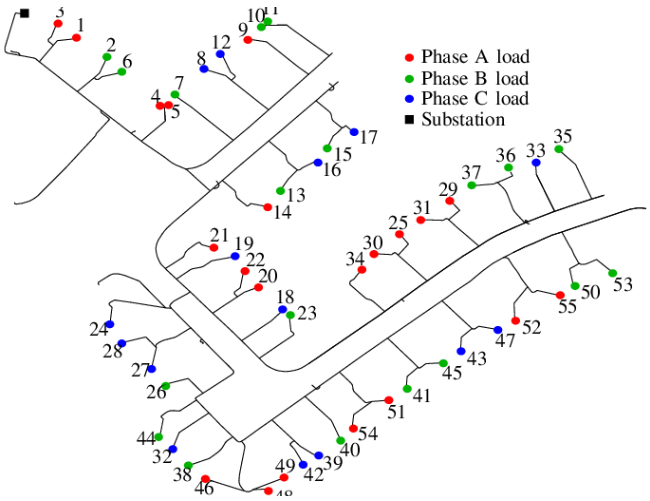


Figure 5-1: The reduced IEEE European LV test feeder.

Operating Envelopes, as detailed in (Marques, et al., 2024), are utilized to calculate the guaranteed power available to each end-user on an LV feeder. The results for a specific NFCA scenario, assuming all end-users enter into agreements with the DSO, are illustrated in the figure below.

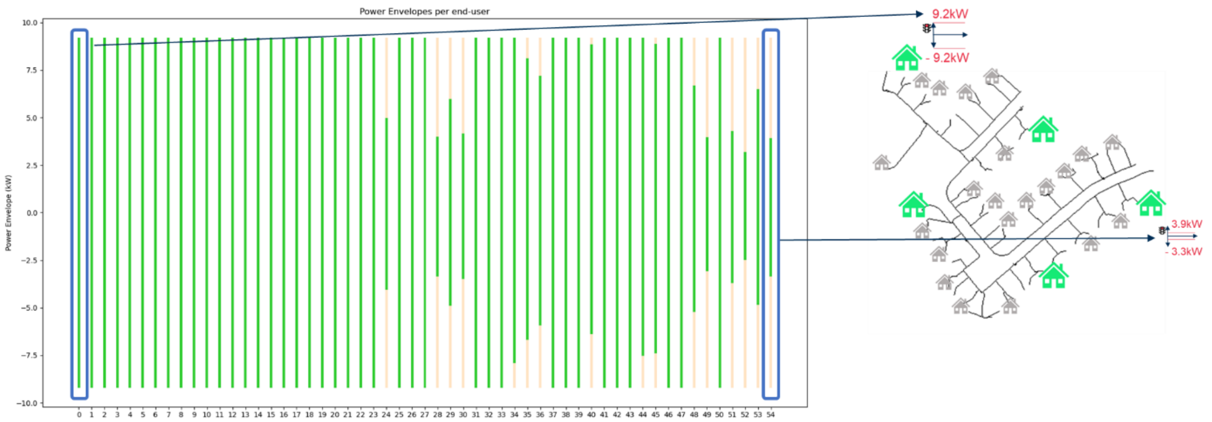
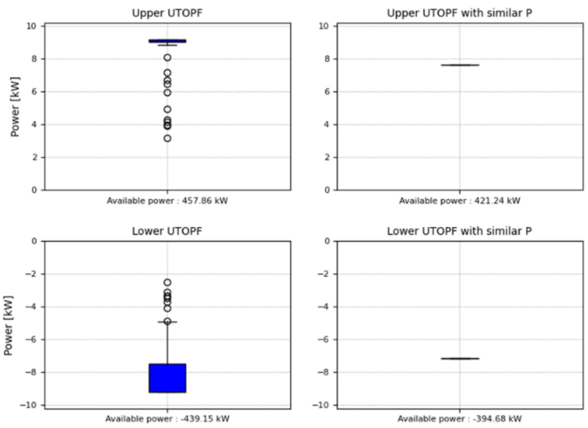


Figure 5-2: Operating envelopes of all end-users.

The figure highlights that end-users located closer to the transformer at the beginning of the feeder can consistently access their full connection capacity (represented by fully green bars). In contrast, an end-user at the far end of the feeder has a significantly restricted guaranteed capacity, limited to 3.9 kW/-3.3 kW.

This situation raises concerns about discriminatory treatment, necessitating complementary rules to ensure fair access for all end-users. One potential approach is to introduce a rule ensuring that all end-users can access the same guaranteed power. This is illustrated in the figure and table below:

- The box plots on the left of Figure 5-3 compare the guaranteed power limits for end-users under two scenarios: without fairness constraints (left) and with equal guaranteed power for all end-users (right).
- The table on the right of Figure 5-3 shows the guaranteed power and the optimized OE for each case. It indicates that the OE limits are approximately 8% higher when calculated without fairness constraints compared to when all end-users have similar guaranteed limits.



Criteria	UTOPF	UTOPF similar
OE	+ 457.86kW - 439.15kW 8% higher than Similar	+ 421.24kW - 394.68kW
Fairness	Low	High
Computation time	70 s	60 s

Figure 5-3: Comparison of guaranteed power limits without fairness constraints and equal guaranteed power.

Figure 5-3 highlights a key trade-off, i.e., ensuring fairness often results in reduced OE capacity. Finally, the guaranteed power limits were recalculated by reducing the number of end-users opting for non-firm connection agreements (NFCAs) with the DSOs. The results, shown in Figure 5-4 below, indicate a clear trend: as the number of end-users participating in NFCAs decreases, the guaranteed capacity diminishes accordingly. In summary, greater participation in NFCAs leads to a more efficient distribution of constraints, reducing the impact on individual end-users.

Figure 5-4: Guaranteed power limits vs number of end-users.

5.2 Case study B – Sibelga grid

Figure 5-5 shows the second grid studied, which is a part of the Sibelga LV distribution grid that includes 3 MV feeders (11 kV) connecting 49 LV feeders with a nominal voltage set at 230 V. There are 712 connection points and 2,267 end-users, meaning that several end-users can be connected to the same grid connection point. Each connection point is represented by a small bar connecting the grid to the building or the house. End-users can be either single or tri-phase connected and are all delta-connected. Maximum connection capacity differs from one end-user to the other, varying from 3.7 kVA (single-phase 16A connection) to 25.1 kVA (tri-phase 63 A connection). End-users are unevenly distributed across the feeders and the phases, which captures unbalanced connections. Finally, note that the distribution grid is found in an urban area, average distance between connection points is 13 m, which influences how current or voltage limits the OE.

Figure 5-5: The Sibelga grid

Figure 5-6 illustrates the guaranteed power per aggregated LV feeder for the Optimal and Fair unbalanced three-phase optimal power flow (UTOPF) methods, represented by light green and dark green, respectively. Additionally, the aggregated connection capacity per end-user is still shown in light orange. To enhance clarity, each feeder's OE and connection capacity are displayed as a single bar because the following relationship holds: **Fair OE ≤ Optimal OE ≤ Connection Capacity**.

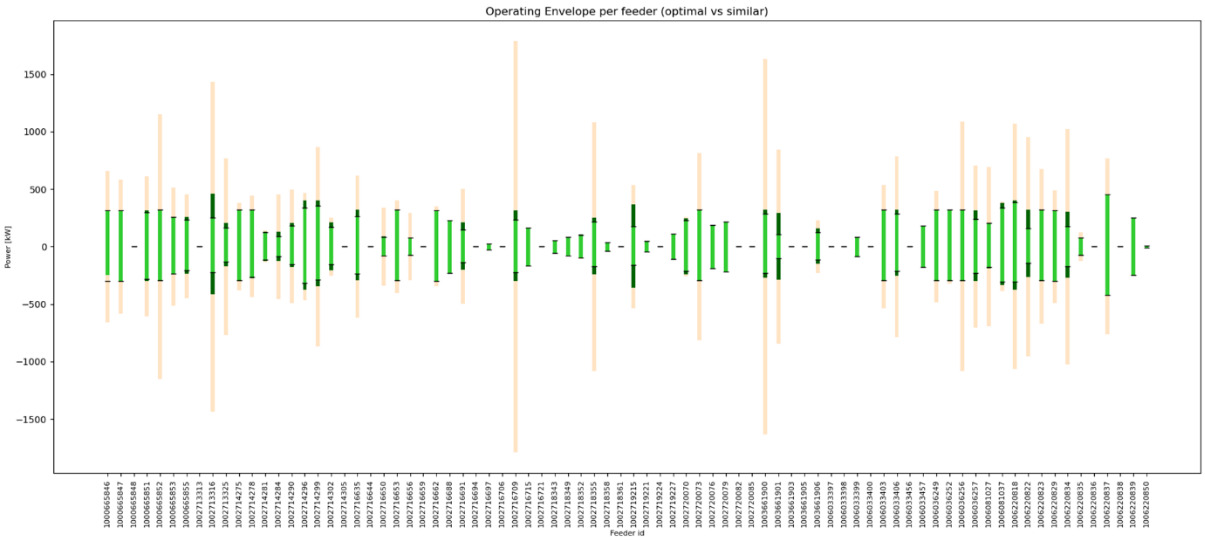


Figure 5-6: Guaranteed power per aggregated feeder based on the optimal (light green) and fair (dark green) UTOPF methods.

From this study, we can classify distribution feeders into three types based on their characteristics, as follows:

Type 1: Feeders Where Optimal and Fair OE Equal the Connection Capacity

- **Description**: Fifteen feeders fall into this category, characterized by their short lengths (58 to 227 meters) and a small number of end-users (1 to 24).
- **Key Insight**: These feeders are oversized, allowing all end-users to access their maximum connection capacity without posing any congestion risks.

Type 2: Feeders Where Aggregated OE for Optimal and Fair Methods Are Equal

- **Description**: This category includes feeders where the aggregated OE is the same for both the Optimal and Fair UTOPF methods, despite variations in OE distribution among end-users.
- **Explanation**: This equality is mathematically possible because the Fair UTOPF method introduces an additional constraint into the optimization problem. This constraint reduces the feasible solution set but does not necessarily alter the aggregated OE.
- **Key insights**: Feeders of type 2 are those where aggregated OE is similar regardless of whether the Optimal or Fair method is used. Figure 5-7 depicts a feeder where the aggregated power guaranteed per end-user is comparable for both the Optimal and Fair methods. In such cases, the inclusion of fairness criteria does not result in a reduction of the aggregated power at the LV feeder level. Although, for each end-user the guaranteed power is subject to change.

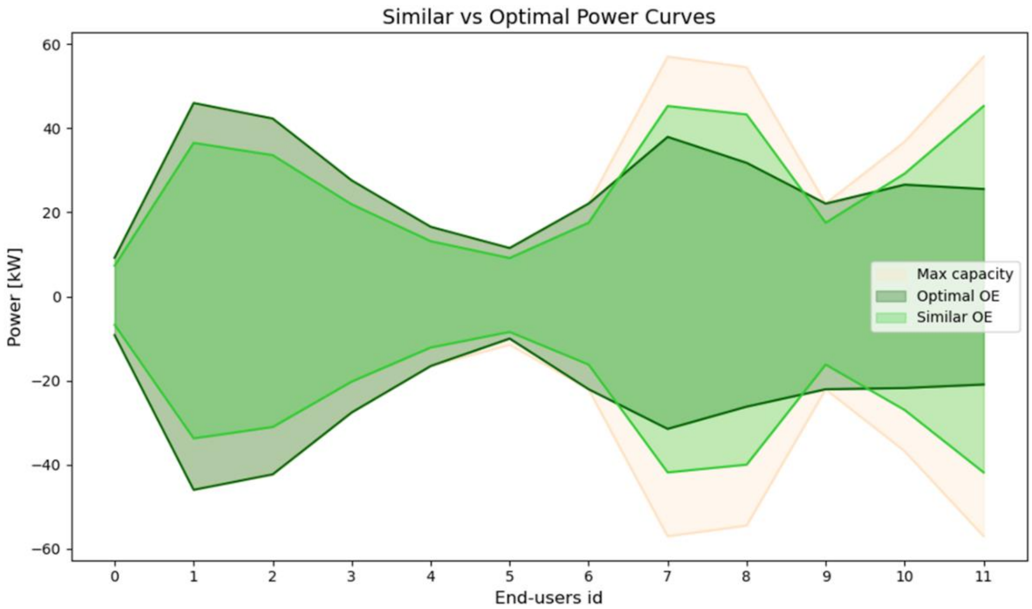


Figure 5-7: Example of guaranteed power for type 2 feeder.

Type 3: Feeders with Significant Differences Between Fair and Optimal Envelopes

- **Description:** This category comprises feeders where the aggregated Operating Envelope (OE) differs significantly between the Optimal and Fair UTOPF methods.
- **Key Insight:** The discrepancy between Optimal and Fair UTOPF results is often attributed to the heterogeneous distribution of end-users along the LV feeder. For example, a representative feeder of this type is shown in Figure 5-8. It features single-family homes distributed along the feeder, with a multi-unit building housing 20 end-users located mid-street at ID 13.

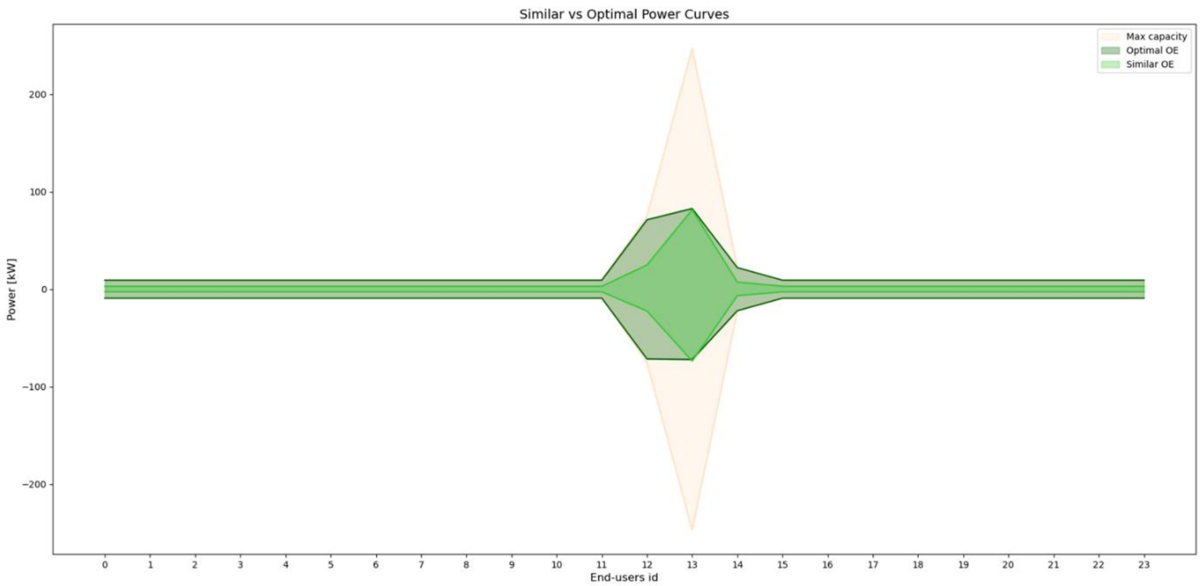


Figure 5-8: Example of guaranteed power for type 3 feeder.

6 Evaluation of coordination schemes in the Belgian context

In what follows, we will deep dive into the four clusters of coordination schemes and apply them to the Belgian context. We will start discussing the situation as implemented today in Belgium (TSO-only procurement). Then we will discuss the changes required to move to a TSO-DSO separate procurement in which the DSO is also procuring flexibility next to the TSO ancillary service markets. Thirdly, we discuss the TSO-DSO joint procurement. Finally, we briefly discuss the most realistic scenario in which market-based mechanisms are combined with implicit flexibility schemes such as tariffs or other flexibility acquisition mechanisms such as connection agreements.

When evaluating these four clusters of coordination schemes, three topics are discussed as illustrated in Figure 6-1.

Figure 6-1: Three topics to discuss per cluster of coordination schemes.

First of all, we will discuss the set-up choices that need to be made when choosing a specific coordination scheme. Table 6-1 gives a summary of the different set-up parameters that we will touch upon in this deliverable. This set-up parameters are in line with the flexibility ingredients as discussed in **Error! Reference source not found.**. The attentive reader will note the differences between Table 6-1 and **Error! Reference source not found.** in the sense that for instance elements such as "consumer engagement and participation", "interoperability and standards", and "technological components" will not be handled in this deliverable. This does not imply that these elements are not relevant, yet are simply out of scope for this deliverable. For each parameter, we will use colour codes to indicate the set-up complexity and challenges. Sticking to the grey table colour implies that this set-up parameter has already been implemented, implying that the BAU situation can remain. **Green** colours refer to a situation where a parameter is (close to being) implemented, implying that transition has already partly taken place. **Orange** and **red** colours refer to parameters that still require, respectively, changes or a lot of changes before the coordination scheme is fully implemented. Especially the red colours point to parameters that should receive priority when implementing a specific coordination scheme.

Table 6-1: Set-up parameters discussed per cluster of coordination schemes.

Set-up parameters	Description
Products & services	Do current products need to be adapted? Do we need new products?
Roles & responsibilities	Who takes up new or adapted responsibilities? What are these responsibilities?
Prequalification & Grid security check	How do we ensure that flexibility is activated in a grid-safe manner for all SOs?
Procurement/activation	How does the market clearing take place?

Remuneration & settlement	How do we verify whether flexibility is delivered and how do we incentivize FSPs?
Transparency on long-term, short-term, and real-time SO's needs and constraints	Where is flexibility needed? Do we know outside our grid what grid constraints are?
Operation Guidelines/ Process Mapping	What are the operational implications for each SO when implementing these schemes?
Data Management & Governance	Which data are needed, and which data need to be shared?

Secondly, when a coordination scheme is set up, it is possible to quantify its performance. While inn Chapter 4, the performance of each scheme is discussed, this chapter will provide a summary and provide further discussion in combination with other parameters. Table 6-2 discusses the parameters that are used to evaluate the performance of the coordination schemes. Similarly to the set-up parameters, we will use colour-coding to evaluate the parameters: green colour refers to positive performance, orange refers to medium performance, and red colour refers to bad performance.

Table 6-2: Performance parameters discussed per cluster of coordination schemes.

Performance parameters	**Description**
Total procurement cost	How much is the market procurement cost for the involved SOs?
Complexity of the market clearing	How complex is it, in terms of mathematical model and solving time, to implement the market clearing for the specific TSO-DSO coordination scheme?
Grid safety of distribution systems	How safe is it, for the local grid, to activate resources at distribution networks?
Market liquidity	What is the impact of the TSO-DSO coordination scheme on the overall liquidity and value stacking of resources?

Finally, we will discuss the feasibility of the different schemes in Belgium. Feasibility is discussed in terms of the parameters described in Table 6-3. Similarly to previous parameters, we will use colour-coding to evaluate the parameters: green colours refer to quite feasible parameters, orange refers to medium feasible parameters and red colour refer to parameters which are judged to be rather infeasible or non-realistic to be implemented (at least in the short-run or in the current environment).

Table 6-3: Feasibility parameters discussed per cluster of coordination schemes

Feasibility parameters	**Description**
Ease of implementation in terms of adaptations needed (products, baselining…)	What adaptations are needed to implement the TSO-DSO coordination scheme?
Compatibility with existing DSO processes	How close to the DSOs' current practices is the TSO-DSO coordination scheme?

Compatibility with existing DSO processes	Can the different steps of the TSO-DSO coordination scheme be sequentially performed and aligned timewise?
Feasibility in terms of timing	Is the TSO-DSO coordination scheme compatible with current regulations? Can it be directly implemented or does it need regulatory adaptations beforehand?
Compatibility in terms of regulation	In what situation the TSO-DSO coordination scheme is applicable?
When do we need this model?	What steps should be taken first to implement the TSO-DSO coordination scheme?

Disclaimer: in this deliverable, we aim to present a general methodology to discuss and compare the different schemes. However, all the discussions touched upon in this deliverable are to be evaluated in much more detail before such schemes can be implemented in practice. In the tables below, more summarized and generic statements are provided, requiring more detailed discussions in practice. Furthermore, for a proper evaluation of the different schemes, a detailed analysis, taking into account grid specifications and contextual parameters, needs to be executed per region. The calculations done in Chapter 0, are done based on a representative grid and provide good initial insights. However, ideally, real Belgian grid data should be used to complement the Belgian discussions.

6.1 TSO-only procurement

In Belgium, DSOs do not yet procure explicit flexibility from their own distribution grid. Generally, all DSOs mostly rely on technical solutions (network configuration), rule-based solutions, connection agreements, and tariff-based solutions. However, for future purposes, they are also investigating market-based solutions. For instance, Fluvius has set up a pilot market, but this is not yet business as usual flexibility procurement. Ores is also currently considering setting up a local flexibility service market in the future.

6.1.1 Set-up

Given the fact that this cluster is already implemented today, it implies that quite some parameters have already been set-up or are being discussed today. This is illustrated in Table 6-4 which summarizes the Belgian context for which the different steps are illustrated in Figure 3-4. From the table, it is clear that when the TSO is procuring flexibility from the distribution grid, from the TSO perspective, there are no significant changes. The TSO can only procure assets that are prequalified by the DSOs. Today, this is done through an NFS and requires adaptations from the DSO side. As discussed in (Marques, et al., 2024), this NFS is currently rather static, but actions are taken in the context of the iCAROS product to have more dynamic prequalification on a more DA basis.

Despite these positive developments, some challenges remain in the current coordination scheme. First of all, before the DSOs can properly prequalify assets for TSO procurement, it is necessary

Table 6-4: Set-up parameters of coordination schemes in cluster 1

Set-up parameters	DSO prequalification	TSO market procurement
Products & services	N/A	TSO opening market for LV
Roles & responsibilities	• DSO as grid constraints forecaster and communicator to TSO (up to real-time when dynamic scheme) • DSO as prequalification responsible • DSO as responsible for the safety of the distribution	• TSO needs to account for DSO grid constraints (for instance through NFS/traffic light/…) • TSO as FRP and MO
Prequalification & Grid security check	Timing: Prior to market clearing Frequency: static (NFS), dynamic (iCAROS – DA)	Can only use prequalified DSO bids on top of its BAU prequalification
Procurement/activation	N/A	BAU
Remuneration & settlement	N/A	BAU through transfer of energy (ToE)
Transparency on SO's needs	• Reduced network representation, partial data • DSO communication of grid prequalification results to TSO and FSP Moving towards more detailed network data/insights	Provide information to FSPs on flex needs (especially when moving to localized provision for TSO, such as congestion management)
Operation Guidelines/ Process Mapping	• NFS set-up • Internal implementation system	Internal system to acquire information and to take it into account
Data management and governance	• Sharing grid data is not required • Prequalification results need to be shared (how and frequency need to be determined) • DSO wants to understand requested TSO services and to have better observability for its own system	

that the DSO has proper insights into its own grid and its related flexibility needs. However, today, especially for lower voltage levels, grid visibility and transparency are very limited. DSOs are, however, working on increasing grid visibility. For instance, RESA is working on a tool to create more detailed insights in their LV grid. Fluvius has set up a "capaciteitswijzer" for the MV grid. These and other efforts to increase visibility are indispensable to properly prequalify assets, but also to move forward towards other coordination schemes (for instance cluster 2 and 3).

Furthermore, grid transparency is not only needed from the perspective of the DSOs, but is also important for FSPs to understand there are opportunities for providing grid services. In addition, when being disqualified, they need clarity on the prequalification results. Finally, the TSO also needs to understand which assets in the DSO-grid he can or cannot rely on.

Finally, when implementing this coordination scheme, there are implications in terms of operational guidelines and data management. For instance, when changing from the NFS set-up toward the iCAROS DA prequalification, internal processes require adaptations and employees might need additional training. Also, in terms of data governance, prequalification results might need to be shared more frequently when moving to a more dynamic type of prequalification (e.g. as in the iCAROS project). However, all these elements require more detailed analysis and are dependent on DSO-internal processes.

6.1.2 Performance

From the performance perspective, this scheme can ensure grid safety at the distribution level as the DSO prequalifies assets before they bid into the TSO market. The DSO usually prequalifies from a worst-case perspective, ensuring that no additional grid issues are created when assets on its grid provide flexibility for the TSO. However, from a market and system efficiency point of view, it is not guaranteed that the TSO can procure flexibility at the lowest total procurement cost. This is because flexibility could be blocked unnecessarily out of precaution by the DSO. Furthermore, by potentially blocking flexibility, market liquidity might decrease and as such create a less competitive market with higher prices. For a detailed numerical analysis of this market scheme, we refer to (Marques, et al., 2024).

Table 6-5: Performance of coordination schemes in cluster 1

Performance parameters	TSO-only procurement (Central 02)
Total procurement cost	Unpredictable: - Could be high in case of inefficiencies and **blocked flexibility** - Could accidentally be low, but not guaranteed
Complexity of the market clearing	BAU
Grid safety of distribution systems	High, often **worst-case scenario** is used
Market liquidity	**Not facilitating value stacking** Might **unnecessarily block flexibility** (depending on the prequalification method)

6.1.3 Feasibility

In summary, looking at both the set-up challenges and the performance, it can be concluded that for Belgium, and most other countries where only the TSO is procuring flexibility, this coordination scheme is rather easy to set up. Only limited coordination is needed and only a few significant changes need to be implemented. However, this scheme is not in line with the NCDR which also requires DSO flexibility procurement. As a result, it is important to point out that the challenges in this scheme are important action points to be able to move efficiently forward towards more advanced coordination schemes. Some of the basic elements that should be set up in this scheme will also facilitate the move forward towards other coordination schemes. Specifically, important attention points in this scheme are:

- To ensure DSO prequalification is done properly, it is necessary to increase DSO-grid transparency to ensure DSOs understand the impact a specific asset can have on its grid security. Having good grid visibility will also facilitate other coordination schemes in which the DSO needs to understand its own grid needs.
- Furthermore, these insights need to be communicated to other stakeholders (both the FSPs as the TSO, and in future coordination schemes maybe also independent market operators (Mos)). To ensure this transparency, ideally setting up a flexibility register for DER should be considered.
- Finally, these two points directly link back to the establishment of a proper data environment through which data can be stored and shared.

Last but not least, when there is an intention to move away from this type of coordination schemes, it is important that there is an open and friendly discussion environment between all stakeholders. Within Belgium, it is fair to say that at times, this can be challenging due to the fact that there are 3 different regions, with 4 DSOs, 3 regulators, and 3 different regulatory provisions. In addition, there is the federal level, with yet another federal regulator and the TSO.

Table 6-6: Feasibility of coordination schemes in cluster 1

Feasibility parameters	**Description**
Ease of implementation in terms of adaptations needed (products, baselining…)	Minimal effort Key challenge for LV remains baselining and ToE Although ideally: set-up of flexibility register for DER
Compatibility with existing DSO processes	High
Feasibility in terms of timing	High, as everything takes place before market bidding
Compatibility in terms of regulation	Non ambitious: - Draft NCDR requires coordination to ensure value stacking and system efficiency
When do we need this model?	• When only TSO is procuring flexibility. • When there are grid visibility challenges and/or not all data are available, an NFS is a good starting point. • When more detailed grid data is available, but cannot be shared, more advanced OE prequalification models are suited.
Priority areas of improvements	• Set up a friendly discussion environment to come to a common vision on the next steps: how to move away from this scheme?

	• Agree on priority areas of improvement and problems to tackle. • Establish proper data environment • Grid visibility

6.2 TSO-DSO separate procurement

As indicated in Section 2.3, some Belgian regions have started progressing toward this cluster of coordination schemes. Fluvius has set up a pilot market and ORES is considering setting one up. This implies a need to progress towards coordination schemes in which both the DSO and the TSO are procuring flexibility. In the short run, both the DSO and the TSO are still working separately in individual/sequential markets.

6.2.1 Set-up

As discussed in Table 6-7, depending on the type of coordination scheme chosen in this cluster, there are different activities that take place in between, before or after the two DSO and TSO markets (for instance prequalification of DSO-bids for the TSO-market, bid forwarding, or ex-post bid correction mechanisms). Table 6-7 adds a column for each of these activities as discussed previously in Figure 3-5.

Given the fact that this coordination cluster is just being implemented in Belgium, many changes are still needed. This is illustrated in Table 6-7 where the red colour in the first column (DSO-market procurement) is clearly indicating that the DSO still has to set up an LFM to procure flexibility. As of today, this market is not standardly set up in Belgium, so all market phases still need to be developed. The flexibility mechanism ingredients, including which product is procured, who is responsible for new activities (such as market operation), who will do the prequalification, how the market is cleared, and how remuneration takes place, must be specified.

Before a DSO can ensure its new market functions properly, it needs to have full transparency on its own grid (needs) and proper data management needs to be in place to organize all the data flows. As indicated in the first coordination cluster, ideally these elements are already set up in the first cluster of coordination schemes so that they form a good basis for the next coordination cluster. A benefit of this second cluster of coordination schemes is that sensitive grid data do not need to be shared. A major focus point in ALEXANDER was to ensure grid-safe flexibility procurement, i.e., the activation of flexibility by one SO would not cause grid issues in another SO grid. However, one way to achieve it is by including network constraints and information of other SOs in a market clearing problem, which is a red flag for many SOs as they consider that network data is sensitive and private information. In this second cluster of coordination schemes, prequalification or a corrective market can help avoid such information sharing while aiming at ensuring grid-safe activation (Ananduta, Sanjab, & Marques, 2024).

Furthermore, given the fact that a DSO is setting up a new market, requiring many new developments, it is in the interest of all stakeholders to align these developments with other existing and newly developed markets. In both the DSO and the TSO market, products, roles, the different market phases (prequalification, procurement, settlement) and other elements need to be defined and established. As explained in (Marques, et al., 2024), alignment of these elements will facilitate value stacking (which should have a positive impact on market liquidity and FSP engagement), and it will decrease system costs as stakeholders gain efficiency through similar approaches.

Table 6-7: Set-up parameters of coordination schemes in cluster 2

	DSO-market procurement	DSO prequalification	Bid forwarding	TSO market procurement	DSO correction market procurement
Products & services	Development of DSO product DSO and TSO products to be aligned/harmonized to allow for bid forwarding, i.e., alignment on product requirements + aggregation				
Roles & responsibilities	DSO = flexibility buyer Other (3rd) party: MO	• DSO as need forecaster (up to real-time for dynamic schemes) or • DSO as prequalification officer or • DSO as communicator of grid constraints to TSO	Other (3rd party): Bid forwarder, possibly bid aggregator	BAU • TSO needs to account for DSO grid constraints • TSO as FRP and MO	DSO = post-qualifier Other (3rd) party: MO
Prequalification & Grid security check	To be developed, ideally in line with TSO qualification	Timing: Prior to TSO market clearing Frequency: static (NFS), dynamic (iCAROS – DA)	• DSO communication of grid constraints to TSO • Aggregation rules in line with prequalification requirements	• Only use prequalification for DSO bids on top of its BAU prequalification • Prequalification process to be aligned with DSO	To ensure TSO bid activation is DSO grid safe: method and timing to be decided
Procurement/activation	To be developed	N/A	N/A	BAU	To be developed
Remuneration & settlement	To be developed	N/A	N/A	BAU	To be developed
Transparency on SO's needs	• Reduced or full network representation • DSO communication of grid prequalification results to FSP and TSO			Same as cluster 1	

Operation Guidelines/ Process Mapping	• Setting up and implementation of the market • Timing challenges
Data management and governance	• No grid data sharing is required • Prequalification results need to be shared (how and frequency need to be determined) • Sharing of market clearing results and updated grid data for DSO ex-post

Looking at which elements should ideally be harmonized first, ALEXANDER argues that in the short run, the low-hanging fruit is linked to **product harmonization** between DSO and TSO markets, and **alignment of prequalification methods**. In Section 6.2.1.2 we zoom in on the topic of product harmonization. On the other hand, under the first cluster of coordination schemes, it was already recommended to kick off a flexibility register as this would also facilitate prequalification activities in the second cluster of coordination schemes. Prequalification in this cluster takes place in three different levels, namely:

- Prequalification is needed within the DSO-level markets;
- Prequalification is needed for uncleared distribution-level bids that could be forwarded toward the TSO market, and;
- Prequalification is needed within the TSO-level market.

From Table 6-7, it can be derived that ALEXANDER states that DSO prequalification between two markets should already been arranged in the first coordination cluster. In Belgium, this is currently the NFS or the iCAROS project. However, as the DSOs are setting up additional prequalification processes in their own markets, alignment with TSO processes is desired.

Apart from prequalification processes, ideally, other processes, such as settlement, including discussions on ToE, and baselining should also be aligned. Currently, some alignment between SOs in Belgium has been done through some initiatives and studies by Synergrid. For example, in 2024, in the context of ToE, a study on correction mechanisms for independent aggregation of DSO endpoints for balancing products (Delnooz, Kaushal, Mason, Sanjab, & Vanschoenwinkel, 2024) has been carried out. However, further work and detailed discussions on baselining, settlement, and their implementation options, which are out of the scope for ALEXANDER, are still needed.

6.2.1.1 Bid forwarding

As previously pointed out, harmonization in prequalification processes (and products, see next section) is important for bid forwarding. Whenever there are multiple markets that are aligned in terms of timing, bid forwarding between markets can take place. In the basic scenario, bid forwarding can be done by the FSP itself. However, in theory, it is also possible to set up an automated bid forwarding process which implies that non-cleared bids from one market are directly forwarded to the other market. As discussed in (Sanjab, et al., 2023), when bids are forwarded from one market to another, an agent needs to be responsible for the bid forwarding itself. The FGDR indicates that the DSOs' LFM are to be operated either by the DSO or by a third party. It could then be one of these actors that would forward bids to the TSO market.

However, before automated bid forwarding is possible in practice, **different conditions/principles** need to be in place, ensuring that when bids are transferred, responsibilities are clear and transparency of the bid chain is ensured:

- **Consent**: First of all, there needs to be consent on a bid-by-bid basis. This is important because not all bids might want to be transferred or because they serve different portfolios or customers.
- **Transparency**: Secondly, and closely linked to the first bullet point, transparency needs to be maintained at all points of the market sequence. A market participant when submitting bids, includes information related to consent and location, and this information needs to remain available when forwarding the bid to another market layer. Simultaneously, the market participant itself also needs to be informed about the fact that his bid is forwarded to a second market layer. In addition, when bids are forwarded, it also needs to be clear whether bids are potentially already selected in other markets when bids are offered in parallel. This transparency is especially important in case bids can be aggregated and/or adapted. For the FSPs, it needs to remain clear why specific bids are (not) accepted, allowing him to optimize his bidding strategy afterward. Disaggregation of information is therefore indispensable.

- **Liability**: Thirdly, the responsibility and liability of the bid forwarding needs to be made clear. For instance, in case bids are not prequalified and yet transferred to another market, it should be clear which actor is responsible for this decision. When an FSP places a bid in the market, he has a certain responsibility. However, when this bid is transferred by a third party, the roles and responsibilities of these actors also must be clarified.
- **Control**: Furthermore, it must be clarified to which extent and under which conditions FSPs still have the right to adapt their bids in terms of pricing and volumes, and whether they still have the possibility to withdraw their bid(s).

In addition, there are many practical elements that should be discussed, including:

- The timing of bid forwarding;
- It should be decided whether bids are forwarded automatically or manually, and which information or tracing information should be linked to the different bids;
- It should be discussed whether the same bid can be transferred to different markets;

The above discussion points should all be included in the discussion of the set-up of bid forwarding mechanisms as it has an influence on many mechanism ingredients, including data governance, roles and responsibilities, prequalification, and settlement.

6.2.1.2 Product harmonization

Product harmonization is discussed in multiple reports and references. Proper product harmonization not only facilitates coordination between system operators, it also facilitates market access for many different providers and it reduces costs and complexities in the procurement process. Finally, from the perspective of the FSP, it increases value-stacking options (Sanjab, et al., 2023) and it facilitates aggregation (Willeghems, et al., 2024).

In the past, product harmonization was applied mostly to existing products, e.g. TSO-flexibility markets (MARI). However, as highlighted by (Willeghems, et al., 2024), product harmonization should also be addressed when defining new flexibility products (services related to congestion management and voltage control), including a locational component. Where possible, such products should be harmonized with existing frequency products. Nevertheless, (Willeghems, et al., 2024) also recognizes the fact that product harmonization takes time and that due to liquidity and maturity differences between DSO and TSO markets, it is likely that it is a stepwise process in which the DSO first kick-starts its own products. Even though the draft NCDR sets a common terminology for products, a balance is needed between product harmonization and customization (Willeghems, et al., 2024). This is also what we see in Belgium where the DSO in the first place develops its own products, independent of the TSO market.

As a result, in (and outside) Belgium, product harmonization is not self-evident to be achievable due to different stages of market development at the different system operators. This is because DSO-flexibility market procurement is very immature in Belgium. The OneNet project summarized key barriers to achieve a harmonized approach for flexibility products in (Troncia, et al., 2023). We discuss their barriers below, applied to the Belgian context.

Table 6-8: Product harmonization challenges

	Challenge?	Explanation Belgian context
Structure of the grid	Yes	In Belgium, there are 4 large DSOs based in three different regions, leading to different grid conditions. The Brussels region is a highly urban area with mostly 220V grids, while the Walloon region is a very rural region. The Flemish region is very diverse

		with both rural and urban areas. As a result, different regions have different service needs.
SO market maturity	Yes	Today, Fluvius is the only DSO who has started testing market-based flexibility (for local congestion). They have set up specifications to test this individually, not consulting other SOs.
Information and comunication technology (ICT) challenges	Yes	The Atrias Central platform, the RTCP and the Flexhub platform are flexibility data platforms in Belgium. Belgium aims to create a centralized data system, although there are still challenges to overcome and the process is not finalized yet.
Unclear product needs	Yes	DSOs are still immature in local flexibility service procurement. In addition, they use a combination of market-based and implicit mechanisms, or consider non-firm connection agreements.
Diverging requirements	Yes	DSO services are very localized, while balancing services does not require local characteristics.
Stage of market development	Yes	Balancing markets are already very evolved and mature, while local service markets are just being implemented and set-up.
Product life cycle stage	Yes	Ores is considering setting up a market while Fluvius has recently set up a pilot market for both a reactive and an active product. On the other hand, RESA and Sibelga are not yet considering a market-based flexibility provision. Meanwhile, Elia has already very well-established and mature products. All DSOs therefore have different levels of maturity in terms of market development.
Competition/liquidity	Yes	Due to the low market maturity and the fact that not in all regions smart meters have been rolled out, markets are still very illiquid.
Political choice	Yes	National regulation has transposed the Clean Energy Package, but is not taking severe actions to pursue its implementation.
Regulatory limitations	Yes	National legislation leaves a lot of room for DSOs to fill in LFMs in a way they desire. In addition, there is regulation at the level of the three regions, and there are 4 different regulators (one is at the federal level and three is at the regional level)
Contextual differences	Yes	Belgium consists of three different regions each of which has a different degrees of roll out and types of digital meters. Grid topologies also differs between the regions.
Additional barriers in Belgium		
Market platform selection	Maybe	Different system operators independently chose their market platforms, leading to different platform requirements. Fluvius has opted for the NODES market platform, while ORES is planning to open a tender to verify which market platform they will choose.

In summary, while it is clear that today, there is still a lack of product harmonization between DSO and TSO markets, it is important that in the short run, this issue is discussed, allowing at least for harmonization between some key product characteristics. In this respect, efforts of both the DSO and the TSO are required.

6.2.2 Performance

The performance of this cluster depends on whether prequalification is done ex-ante the market bidding, or whether some sort of correction is implemented ex-post the market clearing. Having some sort of ex-ante mechanism almost always outperforms the ex-post mechanism. In the ex-ante case, and as discussed in Section 4.3, grid safety can be ensured for the DSO-TSO market sequence as bids that could have a negative impact are blocked (see Table 4-3 until Table 4-6). In case an ex-post correction mechanism are used, one runs into the risk that there is not sufficient flexibility available in real-time to resolve remaining grid issues. However, in terms of total procurement cost, as shown in Table 4-2, in the ex-ante case, there is a loss of market efficiency. This is because, from a system point of view, some important flexibility might be blocked, requiring the procurement of more expensive flexibility. Furthermore, given the fact that there are separate markets, market liquidity might decrease, also having a negative impact on the procurement cost. The ex-post mechanism performs worse as the correction mechanism requires the set-up of a third market which is likely to further increase the procurement cost as more flexibility could be procured over all markets combined. Given the fact that the final ex-post market is very close to real-time, it will also be negatively influencing market liquidity, potentially further increasing the procurement cost. Finally, the fact that there are two markets increases the complexity of the market clearing compared to the first cluster where the market clearing only takes place once. Nevertheless, in the case of a sequential market with an ex-post mechanism, it could be argued that the fact that no prequalification is needed in every round has a positive effect on the market clearing complexity.

Table 6-9: Performance of coordination schemes in cluster 2

Performance parameters	**DSO-TSO with prequalification (Multilevel 03)**	**DSO-TSO with ex-post correction (Multilevel 02)**
Total procurement cost	Could be high due to **separate procurement** and prequalification **blocking flexibility**	Could be high due to **negative impact of one level in another level**
Complexity of the market clearing	**Prequalification** adds complexity Separating problems reduces solving time	**No prequalification at every round needed.** Only ex-post when something goes wrong **Additional level** of market clearing adds complexity Separating problems reduces solving time
Grid safety of distribution systems	Can be **guaranteed**	Can **not be guaranteed**, requires market liquidity Yet, **more accurate real-time data** available to make proper decisions
Market liquidity	• **Partial value stacking of DERs** • Separating markets reduces the liquidity of each level • Might unnecessarily block flexibility (depending on the prequalification method)	• Partial value stacking of DERs • Separating markets reduces liquidity of each level • **Feasibility depends on market liquidity**

6.2.3 Feasibility

The evaluation of the feasibility of this cluster is summarized in Table 6-10. From this table and the previous discussion, it is evident that this second cluster of coordination schemes is more challenging to implement than the first cluster. This is due to the fact that conventionally DSOs (not only in Belgium but in general) do not have to set up a local flexibility market. Therefore, at present, they have a very low level of market maturity. Additionally, FSPs located at a distribution grid are only now starting to offer flexibility services. In the short run, it is therefore likely that also, in this scheme, real TSO-DSO coordination in Belgium is limited to the coordination in the first cluster, i.e., via a flexibility register, prequalification of DSO-connected resources for the TSO-market and proper data infrastructure.

However, it is important to create, in the first place, a vision of how to align further decisions linked to product development and prequalification. It is worth noting that this second cluster of coordination schemes lies in between clusters 1 and 3, i.e., this cluster falls in between the first cluster in which the DSO has no market and the third cluster in which the DSO and the TSO have a common market. This second cluster can be seen as a step up or intermediate step towards the third cluster in the sense that many actions that are to be taken in this cluster (e.g., product harmonization, alignment of prequalification) will also facilitate a possible step toward the third cluster of coordination schemes (in case this is desired).

Table 6-10: Feasibility of coordination schemes in cluster 2

Feasibility parameters	**Description**
Ease of implementation in terms of adaptations needed (products, baselining…)	• New product and new processes at DSO level (DSO-market) • Ideally: harmonization of products, processes and market phases, even if there is no common market. • Important to decide upon how prequalification takes place to avoid counter balancing issues
	• Ideally: set-up of flexibility register for DER • Linked discussions: baselining, ToE
Compatibility with existing DSO processes	New to implement, but ORES and Fluvius are already setting up an LFM
Feasibility in terms of timing	• If DSO-TSO model (yes), although prequalification close to market clearing might still be challenging • If TSO-DSO model (challenge for DSO to run market after TSO and before real-time) • From FSP point of view: markets need to be aligned
Compatibility in terms of regulation	• Different regions and regulators in Belgium complicates harmonization
When do we need this model?	• When the DSO is also acquiring/procuring flexibility • When the market is not mature yet
What is needed to move forward?	• There is a lot of resistance for the common market model, however, for separate TSO-DSO flexibility procurement to be done efficiently, it is important to align many processes in any case • Communication and engagement of all stakeholders

6.3 TSO-DSO common procurement

The third cluster of coordination schemes contains coordination schemes in which the DSO and the TSO achieve the highest level of coordination. As discussed in Figure 3-8, this can be done in 2 ways:

- Either by setting up a single common market;
- Or by setting up a market with bid aggregation.

6.3.1 Set-up

In terms of set-up (Table 6-11), a key element in the common market procurement is to work towards a true common product. This is challenging as both DSOs and TSOs have different needs. Assuming that in the second cluster, no regret actions have been taken toward product harmonization and prequalification alignment, the full transition to a strongly harmonized or a common product could be easier in this third cluster.

In the scenario where the DSO sets up an aggregated curve to be combined in a market clearing with TSO-level bids, it is sufficient to have highly harmonized products instead of the more complex common product. This is more in line with previous steps that could have been taken in the second cluster of coordination schemes. Therefore, in Table 6-11, it is indicated that product harmonization has a green color, while the set-up of a common product has a red color.

In terms of prequalification, in case of the fully common market, grid constraints of both market operators are accounted for during the market clearing itself. This implies developing a new market-clearing model that accounts for grid constraints, implying that grid data of all system operators need to be shared. Today, this is a red flag for most system operators as it would imply keeping grid data up to date on multiple servers, and grid operators are responsible for the security of their own grid. It is for this reason that we coloured this element dark red.

The market with bid aggregation on the other hand only requires SOs to have insights into their own grid, and thus, it does not require the sharing of detailed grid data between SOs. This is an important argument for SOs who cannot or prefer not to share their grid data. However, in this coordination scheme, a new role needs to be specified: the role of the entity that sets up the aggregated curve. If this scheme is chosen to avoid grid data sharing, then, in theory, it can only be the DSO because of his grid knowledge. This is, however, not in line with current regulations.

Table 6-11: Set-up of coordination schemes in cluster 3

Set-up parameters	DSO bid aggregation	TSO-DSO market procurement	Common market procurement	DSO bid translation
Products & services	2 highly harmonized products		Common product	
Roles & responsibilities	- DSO to set up aggregated curves	- MO	In case of the common market: - MO - Data manager	- The same actor setting up the aggregated curve disaggregates bids - Sends bid activation signals or information
Prequalification & Grid security check	N/A	N/A	Prequalification: / Grid security check: in the market clearing	N/A
Procurement/activation	N/A	To be developed	To be developed	N/A
Remuneration & settlement	N/A	To be developed – e.g. split of cost question in case procurement is for both	To be developed – e.g. split of cost question in case procurement is for both	To be developed – e.g. split of cost question in case procurement is for both
Transparency on SO's needs	Insights own DN data	MO simply requires: - data of TSO-level bids - aggregated bids from DNs - TSO needs (e.g. balancing) and possibly grid constraints	Full grid transparency is needed from both SOs	N/A
Operation Guidelines/ Process Mapping	To be developed		To be developed	To be developed
Data and governance	DSO must provide its grid information, constraints and needs to the responsible party (can also be himself)	All bids, including aggregated bids, and TSO needs must be shared to the responsible party	All data and grid constraints to be shared with the market clearing responsible	Market clearing results and aggregation results must be shared to the responsible party

6.3.2 Performance

In terms of performance, it is clear that this cluster of coordination schemes leads to the best results in terms of minimizing procurement cost, in terms of market liquidity, and in terms of securing both grids, as discussed in Section 4.3. This comes however at the expense of a more complex market clearing and requires some additional efforts in terms of set-up (see Figure 4-2). However, it can be seen that the bid aggregation coordination scheme can achieve highly similar results if a proper calculation method is chosen to set up the aggregated bid curve. This is an important conclusion of the ALEXANDER project as the bid aggregation method has less stringent requirements in terms of set-up.

Table 6-12: Performance of coordination schemes in cluster 3

Performance parameters	Bid Aggregation	Common Market
Total procurement cost	Can approximate optimal cost of the common market	Lowest of all schemes
Data sharing requirements	- Grid data do not need to be shared	- Grid data need to be shared
Complexity of the market clearing	High, due to: - calculation of aggregated bid curve - introduction of complex variables in TSO market	High, due to: - full representation of all involved SOs in market clearing - data sharing
Grid safety of distribution systems	Guaranteed	Guaranteed
Market liquidity	High, all bids made available to both SOs (through aggregation)	High, all bids made available to both SOs (though joint market)

6.3.3 Feasibility

In summary, the common market outperforms the market with bid aggregation only slightly. However, from the set-up, it is clear that the common market requires a more complicated set-up, in terms of a fully common product, common market clearing, data sharing, among others. These are requirements that are right now, given the fact that local flexibility markets are only starting to be implemented, still very futuristic for most SOs. It is also to be questioned whether the additional costs of setting up this complex scheme is worth its additional benefits. The market scheme with bid aggregation on the other hand requires less effort as it is easier to build forward on the previous schemes. The scheme would, however, require the DSO to set up an aggregated curve.

Compared to cluster 2, the coordination schemes in this cluster are more complex, implying its realization might be significantly costlier than that of cluster 2. Therefore, these schemes might not be feasible, especially in the near future. However, it is worth emphasizing that the action points in the previous clusters of coordination schemes (such as flexibility register, aligned prequalification, harmonized product, and grid visibility) only facilitate moving upward toward these advanced schemes. Further studies and research are needed to greatly improve the practicality of the coordination schemes in this cluster. Furthermore, grid-specific analysis under actual scenarios is needed to gain insights into the costs and benefits of implementing a co-optimized scheme. For instance, regions with multiple DSOs might face different challenges than regions with only one DSO. In addition, the benefits are highly grid-dependent. More tailored research is therefore needed per grid area and/or DSO as no one-size-fits-all answer can be given. Another key action point to realize a coordination scheme in this cluster is a proper ICT backbone as not only the market clearing process in this cluster is the most complex but also multiple system operators are involved and must communicate with each other apart from with the market participants. Data management and data governance actions taken in cluster 1 and 2 will facilitate further improvements in this cluster. However, in Belgium, as mentioned in Table 6-8, this might remain an open action in cluster 3 that must be dealt with.

Table 6-13: Feasibility of coordination schemes in cluster 3

Criteria	Market with bid aggregation	Common market
Ease of implementation in terms of adaptations needed (products, baselining…)	**Less efforts** needed: - Harmonized product accommodating DSO and TSO needs - No grid data sharing needed	**Many efforts** needed: - Joint product accommodating DSO and TSO needs - Data sharing with MO
Compatibility with existing DSO processes	Could **lead to a close proxy** without all the process difficulties	**Incompatible**
Feasibility in terms of timing	The bid aggregation needs a translation step near-real time (challenge)	Can fit with existing TSO-level flexibility markets
Compatibility in terms of regulation	Bid aggregation process is not defined: **roles needs to be specified**	Foreseen in regulation, however role definition can be challenging
When do we need this model?	When more coordination is needed between SOs to ensure flexibility is used efficiently from a system perspective Variations in terms of this model are possible depending on possibilities for data sharing. More research is needed to further understand trade-off between costs and benefits.	
What is needed to move forward?	• This model is currently not the end-goal • All steps defined before are needed before discussing this	

	• Important to understand that there is not just "one common market" and the variations are possible to facilitate it: it all depends on what needs to be achieved

6.4 Combination of explicit and implicit mechanisms

In reality, the grid is not managed in silos. It is not realistic to assume that SOs only procure flexibility via market-based mechanisms. For instance, they also make use of tariffs and connection agreements. A combination of flexibility mechanisms will therefore always be in place. In Section 3.5 we discuss an implicit flexibility mechanism where specifically we illustrate the BiTraDER project, which combines connection agreements in an LFM, and in general, each country applies grid tariffs (which are therefore always combined with any other flexibility mechanism). The interplay between these mechanisms is therefore intricate. For example, while grid tariffs can influence consumer behaviour broadly, LFMs can target specific local constraints. The simultaneous application of multiple mechanisms may lead to synergies or, conversely, unintended consequences if not properly coordinated, as discussed in Section 3.5.1. Understanding the cumulative flexibility potential and the cost-effectiveness of combined mechanisms requires detailed grid-specific analysis, which is not covered in this deliverable.

Given the diversity of grid configurations and regional characteristics, a one-size-fits-all approach is impractical. Tailored research and scenario analysis are essential to evaluate the effectiveness of different combinations of flexibility mechanisms. This approach enables DSOs to make informed decisions that balance flexibility potential with implementation costs, ensuring efficient and reliable grid management.

In conclusion, while DSOs have a suite of flexibility mechanisms at their disposal, the optimal integration and coordination of these tools necessitate comprehensive, context-specific research to fully harness their potential and achieve a resilient energy system. For this reason, unlike the previous clusters, in this cluster, we do not go into detail about the set-up, the evaluation, and the feasibility of this scheme. This is because there are simply way too many combinations of different flexibility mechanisms, including variations in their implementation, possible. Given all the different combinations, it is also hard to generalize findings. It is therefore important to set up and discuss different grid scenarios to understand the potential of different combinations of flexibility mechanisms and to trade-off this potential with their implementation costs. Given the large diversity in this cluster, more tailored and grid-specific research is needed.

7 Conclusions

This deliverable studies TSO-DSO coordination schemes for flexibility provision of not only system-wide but also local services and evaluates how TSO-DSO coordination is currently being developed in Belgium. To this end, flexibility mechanisms that exist in the literature and in practice are discussed and are grouped into four practical clusters based on the entity that requires flexibility and the type of coordination. These clusters are then analyzed qualitatively and quantitatively, including their relevance within the Belgian context. Furthermore, key measures/action points for setting up each coordination cluster are defined.

Summary of ALEXANDER analyses

The analysis of the TSO-DSO coordination clusters, in the order of increasing cluster complexity, is as follows.

Cluster 1 consists of coordination schemes where only the TSO procures flexibility via an explicit market while distribution-level flexibility resources are allowed to participate in the market. For this cluster, grid prequalification of distributed flexibility is crucial in ensuring its safe activation if cleared. This cluster covers the TSO-DSO coordination that is currently put in place in Belgium where the grid prequalification process is done via a network feasibility study. In this regard, ALEXANDER has proposed an improvement to this prequalification method by using dynamic operating envelopes.

Cluster 2 groups coordination schemes where not only the TSO but also the DSOs have their own flexibility markets. FSPs in distribution systems can participate in their local DSO market and the TSO market. In order to achieve grid-safe activation of distributed resources, either a grid prequalification or an ex-post corrective mechanism can be put in place. Our numerical simulation results show that grid prequalification based on operating envelopes outperforms the ex-post corrective market in ensuring distribution grid safety while market efficiencies of these two methods are case-dependent. Additionally, our conceptual and numerical simulation studies show that the DSO-TSO sequence, i.e., when the DSO market is cleared before the TSO market, is better than the TSO-DSO sequence, not only in terms of market efficiency and grid safety but also feasibility/applicability. In Belgium, as some DSOs are currently developing their own flexibility markets, the coordination between these DSOs and the Belgian TSO is moving toward this cluster.

The coordination schemes in cluster 3 consider co-optimization of flexibility provision by the DSOs and TSO. This can be achieved by either setting up one common market where flexibility is procured to meet the flexibility needs of all system operators or by a market scheme with bid aggregation, which is proposed within ALEXANDER. In the latter scheme, the flexibility needs of the DSOs are taken into account in the creation of grid-safe aggregated bids, which are submitted to a market where the TSO's flexibility request is included. While the common market scheme is the most efficient scheme, as compared to any other scheme, the market scheme with bid aggregation can approximate the efficiency of the common market. Furthermore, the common market scheme is less practical in terms of data management than the market scheme with bid aggregation. In the context of TSO-DSO coordination in Belgium, this type of coordination does not currently exist.

Cluster 4 includes coordination schemes where market and non-market (implicit) mechanisms co-exist. One such implicit mechanism discussed in this deliverable is non-firm connection agreements, which provide non-strict power limits to consumers depending on the states of the distribution network. ALEXANDER has developed a calculation methodology for this mechanism based on an unbalanced three-phase optimal power flow method that can be used for low-voltage consumers. Evaluation of the fairness of the process and characteristics of the grid, e.g., urbanity, is also performed. An important highlight of our analysis is that this mechanism might create a conflict with a market-based mechanism. Thus, an alignment between the system operators is essential when a coordination scheme in this cluster is implemented.

Outlook

Next to the evaluation of the TSO-DSO coordination clusters, this deliverable also defines no-regret action points and further steps required to set up a coordination scheme for each cluster. These action points are defined particularly based on the evaluation of existing TSO-DSO coordination in Belgium. They are summarized as follows:

- Cluster 1: It is important to ensure that there is a proper grid prequalification and ideally a flexibility register. To this end, the DSO must invest in acceptable grid transparency tools to increase grid visibility. This can be facilitated by including the ability for the SO to use the smart meter information for grid planning and operation purposes, which directly pinpoints a last key action point, which is data governance and sharing.
- Cluster 2: DSOs need to have proper grid insights to determine where flexibility is needed. Similarly, a flexibility register becomes even more important when multiple system operators can utilize the same flexibility assets. Furthermore, when coordination increases in this second cluster, data sharing further becomes increasingly important as multiple stakeholders need to be informed. Therefore, the action points in cluster 1 remain essential. On top of these actions, it is also important to prioritize product harmonization and prequalification alignment since assets will be offered in multiple markets.
- Cluster 3: The co-optimization process requires the action points in clusters 1 and 2 to be performed well. In fact, especially under a common market scheme, its product must be agreed upon by all system operators, going beyond product harmonization in cluster 2. Furthermore, this cluster requires a well-defined underlying ICT system to run the mechanism properly. Additionally, due to the complexity of the market schemes in this cluster, further detailed studies on the flexibility requirements, taking into account the specificity and the context of where the market is set up, are needed. Additional research is also desired in terms of alternatives to the common market scheme, including the market scheme with bid aggregation, which is developed in ALEXANDER, since the practicality of this scheme is still far from satisfactory, albeit it has promising performance and benefits.
- Cluster 4: It is important to properly investigate specific flexibility combinations applied in the grid by the SOs in line with different grid scenarios. It is also crucial to properly identify the flexibility potential of the independent and combined flexibility mechanisms that are set in place. This will facilitate understanding the trade-off between their benefits and their implementation costs. In this regard, one needs to account for all different types of flexibility mechanisms in the grid investment plans (both implicit and explicit flexibility).

As can be observed, the action points of a less complex cluster (lower cluster) are also important for the more complex ones (higher cluster). Therefore, one can move from one coordination cluster to a more complex one, gradually improving their TSO-DSO coordination. This action requires some essential ingredients, including the previously mentioned no-regret measures, to be in place. As a final remark, some key ingredients for flexibility markets that have not been investigated in this deliverable, such as settlement, ToE, baselining, and the underlying ICT architecture, are also indispensable market design decisions that have to be discussed among the system operators.

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