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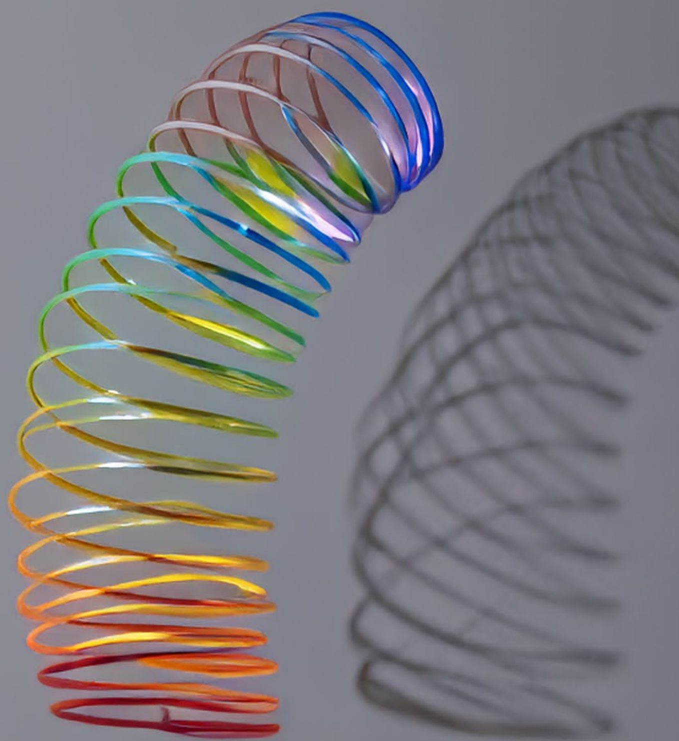
The role of electricity distribution systems in assessing flexibility needs



Flexibility Needs Assessments according to the Energy Market Design reform

Cadenovic, R., Landeka, J., Pozo Camara, D., Vitiello, S.

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Contact information

Name: Josipa Landeka
Address: European Commission – JRC, Westerduinweg 3, 1755 LE, Petten, The Netherlands
Email: josipa.landeka@ec.europa.eu

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Abstract

This report delves into the role of distribution systems in the flexibility needs assessments (FNAs) that will be part of national and pan-European assessments by 2026, as stated in the recently adopted Electricity Market Design Regulation. Transmission System Operators (TSOs) and Distribution System Operators (DSOs) need to jointly work on defining the methodology and facilitating the provision of future FNAs. This report focusses on distribution side, highlighting the elements needed for such assessments and key concepts that could help to profile a methodology.

The analysis explores three primary approaches of TSO and DSO interactions: bottom-up (DSO needs), top-down (TSO needs), and a combined hybrid model. The bottom-up approach emphasizes local flexibility through microgrids, demand response, and energy storage, while the top-down approach addresses the broader transmission system needs. The hybrid model integrates both perspectives, promoting bi-directional data sharing between DSOs and TSOs to manage flexibility across the entire grid. The report concludes that the hybrid model offers the most comprehensive solution, balancing local and national flexibility demands, and calls for regulatory frameworks that promote standardization, protocol development, and enhanced coordination between system operators.

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Authors

Rade Čađenović, David Pozo Camara, Josipa Landeka, Silvia Vitiello

Executive summary

Flexibility in the context of power systems, refers to the capacity to adjust generation and demand in response to varying conditions, particularly as renewable energy sources like wind and solar become more prevalent. As these sources are inherently variable, maintaining a balance between supply and demand is crucial to avoid disruptions such as blackouts. Flexibility allows for rapid adjustments to changes in electricity generation and consumption, which is essential for integrating distributed energy resources (DERs) into the grid effectively.

The report explores the role of distribution systems in **Flexibility Needs Assessments** (FNAs) and suggest key components for creating a methodology to assess flexibility needs that considers distribution systems and is aligned with the European **Electricity Market Design Regulation** (Reg. 2024/1747). The Regulation underscores the necessity for EU countries to assess flexibility also specifically taking into account the reality of distribution systems, as by evaluating flexibility at this level, utilities can better manage local grid congestion, optimize the use of DERs, and enhance overall system reliability and performance.

This report provides an in-depth analysis of the essential elements for designing a methodology to assess flexibility needs in power systems, including coordination between Distribution System Operators (DSOs) and Transmission System Operators (TSOs).

The **Flexibility Needs Assessments** – **FNAs** at national level will be carried out by the various TSOs and DSOs of Europe in the very next years, starting from 2026 as mandated by the Regulation. Given the novelty of such an assessment, the **JRC** – Joint Research Centre of the European Commission started laying down the foundations for a scientifically sound assessment methodology, at the request of **ACER** – Agency for the Cooperation of Energy Regulators (who is tasked with approving the methodology once it has been drafted by the SOs).

This report therefore helps in framing the approach to assess flexibility focusing especially on the integration of Distribution Systems into the assessment, and identifies three key approaches: **bottom-up (DSO needs)**, **top-down (TSO needs)**, and **hybrid** (integrating both perspectives). The hybrid approach is considered the most comprehensive, as it captures the impact of local flexibility resources on the larger grid and allows for bidirectional information flow between TSOs and DSOs.

This report also emphasizes the need for standardized communication protocols, interoperability between systems, and advanced forecasting capabilities to enable the integration of Distributed Energy Resources into flexibility markets. It also highlights the importance of coordination mechanisms, such as collaborative platforms, to facilitate communication and cooperation between TSOs and DSOs.

Overall, the report concludes that a hybrid flexibility assessment approach, which integrates both top-down and bottom-up methodologies, provides a robust framework for addressing both local and national flexibility demands, and recommends that such aspects are taken into account by the European TSOs and DSOs when designing their methodology.

In conclusion, assessing flexibility at the distribution level is not merely a regulatory requirement; it is a strategic necessity for future-proofing electricity systems against the challenges posed by increasing renewable penetration and evolving demand electrification. By adopting a sound scientific approach in such assessments, EU countries can foster a more resilient energy landscape that supports both sustainability goals and competitiveness.

1 Introduction

The most recent European Electricity Market Design (EMD) reform[1] seeks, among many other objectives, to enhance the integration of renewable energy sources and promote flexibility across the EU. The increasing penetration of Distributed Energy Resources (DERs) and renewable energy sources in power grids has significantly altered the operational landscape of both transmission and distribution systems. As the power generation becomes more decentralized and variable, taking place at multiple voltage levels, flexibility becomes essential for maintaining system stability, reliability, and increasing efficiency of the power system as a whole.

A key element of the EMD reform is the emphasis on national flexibility needs assessments (FNAs), which aim to evaluate the flexibility needs of Member States and ensure that both transmission and distribution networks are capable of responding to evolving grid conditions. While Transmission System Operators (TSOs) traditionally managed flexibility on a broader, national level, Distribution System Operators (DSOs) are responsible for local flexibility services due to the proliferation of DERs, electric vehicles, battery storage systems, and demand-side management programs. In this report, different approaches on how to account for congestion management and operational needs of DSOs are examined.

This report explores the fundamental elements for the provision of a flexibility need assessment methodology that is aligned with the EMD requirements considering the coordination between DSOs and TSOs. Three methodological frameworks are proposed: bottom-up (DSO needs) approach, a top-down (TSO needs) approach, and a hybrid approach that integrates both perspectives. These approaches are crucial for addressing the operational challenges presented by local congestions in distribution networks while ensuring that flexibility services align with the needs of the larger transmission system.

This report provides insights into the potential benefits of distributed flexibility and the challenges for its implementation.

[1] Regulation (EU) 2024/1747

2 Flexibility for distribution systems

Flexibility, in the context of electrical distribution systems, refers to the grid's ability to adapt to sudden changes in supply and demand, accommodate variability from renewable sources, and manage unforeseen disturbances like generation shortfalls and demand surges.

Distribution systems' role in flexibility provision is to facilitate integration of both centralized and decentralized energy resources, ranging from large-scale renewable power plants to small-scale DERs, including rooftop solar photovoltaic (PV) systems, wind turbines, battery energy storage systems (BESS), electric vehicles (EVs), and demand response (DR) programs. By combining distributed assets, distribution systems enable local generation and consumption and reduce reliance on the transmission system. Additionally, distribution systems support flexibility by enabling bidirectional power flows and advanced grid management such as demand-side flexibility.

2.1 Key elements of flexibility assessment in distribution systems

This chapter describes some of the most crucial aspects that should be taken into account when designing a methodology to assess flexibility needs including also the distribution part of the power system. Without entering into the details of why each single feature is important for such an assessment, each subchapter provides references to the most relevant experiences in each single feature mentioned. As power systems evolve, additional aspects can be considered.

2.1.1 Demand-Side management

Demand-Side Management (DSM) programs encourage consumers to alter their energy usage level and patterns to benefit the overall power system performance. DSM can provide flexibility required to balance electricity generation and be used as a tool for increasing energy system flexibility and supporting the integration of variable renewable energy sources (Lund et al., 2015). Flexibility assessment should account for the potential of DSM to alleviate peak demand and integrate intermittent renewable energy. Growing importance of flexibility assessment in distribution systems is demonstrated through the following projects:

- GOPACS, a TSO/DSO coordination platform for solving network congestions, operating in the Netherlands ("About GOPACS," 2024).
- The enera Flexmarkt, a smart energy showcase focused on network congestion management, operating in Germany (Brommelmeier et al., 2021).
- The sthlmflex project, aims to demonstrate the potential of local flexibility markets and enhance coordination between TSO and DSOs, operating in Sweden ("Sthlmflex," 2023).
- Demand Flexibility Service (DFS) by NG ESO, aimed to incentivise users through suppliers/aggregators to voluntarily reduce or flex their demand (Energy UK, 2023).
- California Independent System Operator (CAISO) Flexible Ramping Product, to help balance the grid during periods of high renewable energy generation (Gergen et al., 2024).
- EcoGrid EU, a distribution grid project on distributed energy resources and flexible demand response to real-time price signals (Jorgensen et al., 2011).

2.1.2 Energy storage technologies

Energy storage technologies have the potential to play a significant role in the future distribution system and should be considered in flexibility assessments (Alipour et al., 2022). Energy storage systems can reduce the strain on a distribution network during peak hours and increase the use of renewable energy generation assets. Batteries especially can quickly respond to supply and demand fluctuations and provide backup power. Storage systems can be easily integrated with various energy management: demand response programs, microgrids or virtual power plants, improving grid resilience. Energy storage is also considered essential for network stability and efficiency and can offer an alternative to traditional network expansion (Fraunhofer ISI et al., 2023).

As energy storage plays a critical role in providing flexibility, assessing the capacity, location, and deployment strategy of energy storage systems is essential to maximize their benefits. More on flexibility provided by energy storage can be found in the literature (JRC, 2023; Lund et al., 2015).

2.1.3 Advanced smart grid technologies

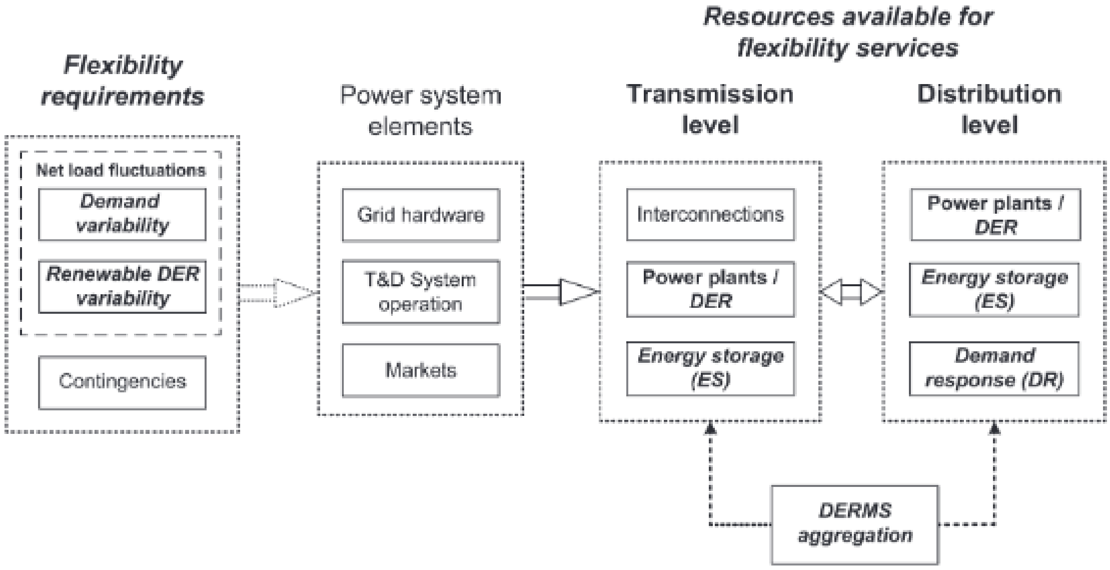
Smart grid technologies, such as advanced metering infrastructure and distribution automation, enable real-time monitoring and control of the grid, contributing to flexibility. It is also extended to TSO-DSO coordination platforms that show load profiles and operational constraints at the delivery points between system operators. Coordination between TSOs and DSOs through smart functionalities, such as real-time monitoring and network management are crucial for optimal infrastructure utilization and distributed generation inclusion (CEDEC et al., 2021).

2.1.4 Distributed energy resource management systems

Distributed Energy Resource Management Systems (DERMS) could be instrumental in managing the increased need for flexibility in power systems by managing the variability and uncertainty introduced by DER. DERMSs aggregate individual DER and demand response resources, simplifying their management by presenting them as fewer aggregated virtual resources (IEEE Power and Energy Society, 2021). Because they focus on the location of each generation asset, thus DERMS typically include local grid management making them different to the Virtual Power Plants (section 2.1.8).

Uncertainty in net load fluctuations together with eventual grid element contingencies increase flexibility needs. System demand, grid components (e.g. distribution and transmission lines) and electricity markets are impacted by flexibility requirements. By introducing DERMS, additional flexibility services (besides markets) could be secured on both transmission and distribution level (**Figure 1**. Flexibility requirements and resources—distribution and transmission).

Figure 1. Flexibility requirements and resources—distribution and transmission



Source: (IEEE Power and Energy Society, 2021).

2.1.5 Grid-Scale renewable integration

Large-scale renewable energy production is often located in geographically remote areas and might be severely influenced by transmission grid limitations. Power flows from such RES generation to the distribution grid can create congestions when production exceeds local consumption. Evaluating large-scale renewable energy impact on distribution systems helps in planning necessary upgrades and operational strategies to ensure grid balance. through a combination of *grid-friendly*[2] renewable generation, conventional generation flexibility, demand response, and energy storage systems (IEC, 2012).

2.1.6 Electric vehicles

Integration of electric vehicles (EVs) on a large scale affects distribution grid planning and operation but also offers opportunity for additional flexibility service using vehicle-to-grid (V2G) technology. Strategy objectives for DSOs include congestion and voltage support, power losses minimization, valley filling and phase balancing (Gonzalez Venegas et al., 2021).

Congestion and voltage management can be done by utilising smart charging and V2G to participate in demand response programs.

[2] "RES generation can be made more predictable, controllable and dispatchable, or in other words more grid-friendly, by improving the design, operation and modelling technology at the generating unit, plant and plant cluster level." (IEC, 2012)

2.1.7 Smart home appliances

Smart home appliances can offer flexibility by participating in demand response programs by adjusting consumption around peak and off-peak hours. Home systems with integrated battery storage can help with consumer's reliance on grid based on real-time signals from distribution grid.

Heat pumps can participate in demand reduction during peak hours by load-shifting (preheating or precooling around peak hours). Aside from demand response, heat pumps can be paired with thermal storage system, or synchronized with solar or wind production, reducing their reliance on the grid.

2.1.8 Virtual power plants

Virtual Power Plants (VPPs) offer flexibility trough aggregation of various DERs including solar and wind generation, battery storage systems, electric vehicles and smart home appliances. VPPs are equipped with smart control systems and require advanced communication infrastructure to achieve real-time coordination with grid operators. VPPs do not see location of aggregated generation assets as their main grid objectives are frequency stabilisation and peak load management.

Due to the bidirectional information and energy flow, VPPs provide more dynamic and resources to the grid, and, connected to microgrids, could reduce grid reliance.

2.2 Distributed flexibility potential, benefits and challenges

Distributed flexibility refers to the capacity of decentralized energy resources to dynamically adjust their generation or consumption patterns in response to grid signals, thereby providing a range of operational flexibility services to the power system. These resources include demand response, distributed energy storage systems, and small-scale renewable generation.

The integration of distributed flexibility into the grid offers multiple **advantages**:

- **Quick response to local fluctuations:** Distributed resources can respond rapidly to changes in local supply and demand situation, thereby contributing to the overall balance of the energy system. Their proximity to consumption points allows for more efficient regulation of energy flows, reducing the need for time-intensive interventions from centralized sources.
- **Reduced losses:** By addressing supply-demand imbalances at the distribution level and by increasing self-consumption, distributed resources can reduce the need for energy transmission, which is often associated with energy losses and inefficiency.
- **Grid reliability and resilience:** Distributed flexibility improves system reliability by diversifying the sources of energy generation and storage. They contribute to the resilience of the energy system by providing alternative sources of power in the event of centralized generation outages or transmission constraints.
- **Mitigation of renewable curtailment:** Flexibility provided by distributed energy storage systems and flexible loads reduces the curtailment of renewable energy generation. By storing excess generation from RES, distributed flexibility helps optimizing RES usage.

While distributed flexibility offers significant advantages to electricity systems, there are **constraints and risks** associated with relying on distributed flexibility especially when scaling it for larger grid management:

- **Complexity in Integration:** The integration of DERs into the national or pan-European grid management systems presents significant technical and operational challenges. The variability and unpredictability of DERs, especially those dependent on intermittent renewable energy, complicate grid modelling and require sophisticated algorithms to forecast and manage their output.
- **Communication and Control Infrastructure:** Effective coordination of DERs necessitates robust communication and control infrastructures, capable of managing the real-time exchange of data and instructions between grid operators and flexibility providers. This is particularly challenging in systems with numerous small-scale resources, spanning multiple jurisdictions and operators.
- **Modelling and Forecasting Challenges:** Achieving accurate modelling and forecasting of distributed flexibility at the local level is difficult due to the high granularity and variability of data required, which may not be easily scalable or applicable at a DSO level. Advanced forecasting tools and machine learning algorithms are required to address these complexities, but their effectiveness depends on the availability and quality of real-time data.

3 Flexibility needs concepts for the methodology

This section introduces key concepts necessary for assessing flexibility needs within distribution systems. The transition toward decentralized power generation requires both local and global approaches to flexibility, particularly meeting both TSOs and DSOs needs. The aim is to provide basic framework for understanding the flexibility requirements and needs at different levels of the power grid and offer starting points for deeper discussions on how to approach flexibility needs assessment.

One of the main points, when discussing distribution needs, is distribution-level congestions and how DSOs and TSOs can coordinate flexibility services. By introducing hybrid methodology approach, both DSO and TSO perspectives and their strengths are integrated, offering the best outcome from three analysed methods.

3.1 Local vs. global flexibility needs

Flexibility can be characterised as either *local* or *global*. Local flexibility refers to resources that act exclusively within a confined area; for example, a battery installed at an industrial facility with the sole purpose of addressing issues specific to that industrial load. However, from a broader perspective, only global flexibility is of interest for this discussion of flexibility needs. With this in mind, the focus of a methodology is identifying/quantifying the flexibility needs that can provide wider benefits of flexibility, i.e., characterized as global. While some resources, such as batteries, or DRs, may not directly benefit locations far from their own, they do create complementarities with the system by providing indirect benefits to the distribution grid. Even more, elements within distribution grids that can offer flexibility to the system, such as a large population of heat pumps, electric vehicles, etc., can be considered part of the flexibility solutions if they demonstrate system-wide benefits.

3.2 Flexibility needs and local flexibility markets

The term 'local flexibility markets' refers to all types of market-based procurement of flexibility services by DSOs, irrespective of their architecture (e.g. spot markets close to real time as opposed to long-term tenders) and operational status (e.g. business as usual as opposed to pilot projects). In all of the markets reviewed, the DSO(s) is (are among) the buyer(s) of flexibility services, but other players (e.g. the TSO) may or may not, depending on the case, also procure flexibility services from distributed resources (Chondrogiannis et al., 2022). The types of possible flexibility services and buyers are summarised in Table 1.

Table 1. Possible flexibility services procured by different actors in selected local flexibility markets

Type of flexibility	Buyer of flexibility services	
	DSO	**TSO**
Congestion Management (Distribution System)	X	
Voltage control (Distribution System)	X	
Reliability enhancement (Distribution System)	X	
Network deferral (Distribution System)	X	

Type of flexibility	Buyer of flexibility services	
	DSO	TSO
Frequency control (balancing)		X
Congestion management (Transmission system)		X

Source: (Chondrogiannis et al., 2022).

TSO's need for flexibility comes from system balancing, while DSO's comes also from balancing but it is accentuated mainly from grid issues (congestion and voltage profiles limits). This was showcased in several projects where DSOs took more active role as a buyer or facilitator of flexibility resources like GOPACS, the enera Flexmarkt and the sthlmflex project mentioned in 2.1.1.

The JRC report on Local Flexibility Markets in the EU (Chondrogiannis et al., 2022) provides an in-depth analysis of local flexibility markets and use of flexibility at distribution level. Several key points from the report that are highlighted are TSO/DSO priority in provision of flexibility services and network violations management with activation of flexibility.

In one of the examples, enera Flexmarkt, the focus is on local flexibility markets for the provision of services to DSOs, but the market platform can also be used for the provision of services to TSOs, leading to formation of priority rules between the different network operators. Coordination between network operators follows a cascading top-down approach. The upstream system operator communicated the required power procurement via the marketplace and reported any network congestions to the downstream operator. The downstream operator then processed this information and provided the corresponding capacity constraints, specifying the maximum amount of power that the upstream operator could procure from each local market area. This also effectively meant that the downstream network operator had priority regarding the utilisation of flexibility potential in its network.

In another example, the COPACS project, congestion management is achieved through a system that integrates flexibility procurement from various market platforms. Grid operators pre-announce their flexibility needs to solve congestions in specific areas and use their own tools and processes to determine congestions and to evaluate the potential contribution of orders with location indication to solve the transport restriction. The process involves grid operators procuring energy sell orders in congested areas while simultaneously activating energy buy orders in non-congested areas. This approach prevents congestion without creating new imbalances elsewhere in the network.

3.3 Mechanisms of flexibility: ability to respond and energy shifting

Before delving deeper, it is essential to differentiate between the two most fundamental ways of flexibility provision, i.e., building blocks that can take part of a methodology to integrate DSOs capabilities into the FNAs.

1. **The capacity to respond**: This involves reacting to specific events that require rapid adjustments (increase/decrease supply or demand), such as high ramping needs, reserve provision. Typically, this response occurs within a specified timeframe, e.g., 1 day and has a given resolution, e.g., 1 hour.

2. **The capacity to shift energy**: This can be viewed as a "buffer" for the system, enabling the transfer of energy from generation points to consumption areas. Storage and demand response are clear examples of technologies that fit this definition. However, the upgrade or expansion of the power grid can also contribute to also shifting energy across space, balancing consumption with supply.

Quantifying flexibility potential from elements that primarily enable deliverability is not recommended, such as grid updates[3], due to their separate assessment processes, as they are included in the distribution network development plans. However, it is important to highlight considering these flexibility enablers within the methodology. Thus, such infrastructure role in facilitating flexibility in distribution grids should be considered in the FNA methodology.

3.4 Flexible integration of DSO capabilities

Considering the large number of DSOs in Europe and the diversity among them (Meletiou et al., 2023), the JRC considers beneficial for the future methodology to offer the integration of DSO flexibility to varying extents. This allows each DSO to choose the level of integration that best suits its capabilities, without affecting on the integrity of the FNA. Those levels can be part of an evolving process where DSOs transition to more advance representation of flexibility potential. We propose three possible levels of increasing integration:

— **Simplified:** At this level, the distribution grid has no possibility of asses its flexibility potential (expected for the smallest ones only). The data generated can be extrapolated from other distribution grids that share similar characteristic. The extrapolation would require using common grounds, like population, type of clients that are served, location, etc. This is the minimal level of information exchanges.

— **Medium:** This intermediate level begins to incorporate some aspects of flexibility from the distribution grid. It could include, for example, the identification of flexible loads that can adjust their consumption patterns within certain parameters or the inclusion of small-scale storage solutions that are capable of contributing to grid stability. At this level, only ranges up/down values could be provided by the DSOs for the FNA.

— **Advanced:** A more sophisticated level of representation models the distribution grid operations as a series of equivalent resources. In this case, not a range (min and max limits) is given, but a flexibility capability domain.

3.5 Distribution level congestions and resources in the FNA

The growing integration of DERs at the distribution level presents both challenges and opportunities for increased flexibility in power systems. The flexibility assessment methodology must incorporate approaches that accommodate distribution-level dynamics to optimize the utilization of local

[3] It is worth considering additional elements that enhance the *deliverability* of the technologies with capabilities to respond and/or to shift energy. These elements can include capacitor banks, upgrades to substations, or even the utilization of topology reconfiguration strategies.

resources. Three key approaches: bottom-up, top-down, and hybrid offer different perspectives on how to account for congestion management and operational needs of DSOs.

3.5.1 Bottom-up Flexibility Assessment - DSO needs assessment approach

The bottom-up approach begins by evaluating individual components and their characteristics to estimate the overall flexibility potential. This method encourages aggregation of local flexibility resources at the TSO/DSO interconnection allowing small-scale flexibility resources (e.g., residential batteries, demand response) to participate in national flexibility mechanisms.

One of the core advantages of this approach is its capacity to unlock significant local flexibility resources, particularly through networked microgrids equipped with a surplus of DERs. These microgrids can serve as autonomous systems or provide ancillary services to the DSO to address operational constraints. The main difference between a microgrid operation and DER aggregation is a clearly defined geographical boundary of a microgrid and an ability to serve as a micro power system of their own (IEEE Power and Energy Society, 2021; Strezoski, 2023).

Flexibility assets in form of DERs may cause violations in distribution network, which will require of DSOs to take a more active role. In bottom-up assessment approach, DSO interest would be prioritized as factors like network topology, constraints and localisation of RES would be taken into account only from the DSO level. Such data would be transferred to TSO and leave no room to TSO to request more flexibility than it is previously reported. In this context, DSO may use the potential flexibility resources for its own flexibility needs (compete with TSO) and make the rest available to the TSO.

Key elements for effective bottom-up implementation include:

- **Standardization and Protocol Development:** Standardized communication protocols development and interoperability standards are essential for connecting and operating aggregated DERs at scale. The absence of global standards (Strezoski, 2023) remains a critical barrier to the full integration of DERs into national flexibility frameworks.
- **Resource Identification and Aggregation:** In the context of a bottom-up approach to flexibility implementation, aggregation mechanisms, like DERMS, virtual power plants (VPPs) or community energy management systems, play a crucial role in coordinating and optimizing the contributions of various DERs and DR resources to enhance the overall flexibility of the distribution network. These mechanisms help in aggregating individual DERs and DR resources, enabling them to participate in the flexibility market and providing a unified interface for DSOs to manage the system more effectively.
- **Advanced Forecasting Techniques:** Predicting the availability of flexibility resources at the distribution level requires high-quality data, such as real-time measurements from smart meters. Bottom-up forecasting enhances accuracy but is dependent on the availability of digitalization tools and localized data resources. Example of such forecasting is CAISO combining solar irradiance values and weather predictions to forecast power output for the entire state in order to predict total contribution of behind-the-meter solar plants to its grid (IRENA, 2020).

3.5.2 Top-down Flexibility Assessment Approach - TSO needs approach

Conducting a high-level assessment of the transmission grid's flexibility requirements, takes into account following key components:

— **Integration of large-scale renewable energy:** Transmission grid flexibility requirements (large ramps in variable generation output) are influenced by unpredictability and variability of wind and solar generation. Renewable energy and demand forecasting is based on historical weather patterns, consumption data, and real-time analytics. With algorithm improvements and use of AI, generation forecasts become more accurate and increase time granularity for short-term predictions (IRENA, 2020).

— **Infrastructure flexibility and interconnections with neighbouring grids:** Transmission grid congestion management is influenced by RES locations and grid topology's ability to evacuate energy. The flexibility available from a generator, interconnection resource, or storage device is dependent on its production schedule and its location in the network (Lannoye et al., 2015).

— **Overall demand and supply dynamics**: Volatility in both consumption and production are tackled with demand-side programs and flexible generation like fast-ramping gas plants and energy storage.

— **Evaluation of market framework and mechanisms**: Incentive-based schemes like demand response, energy storage and fast-ramping gas turbines are used to ensure transmission grid's flexibility. Market frameworks can further incentivize the participation of DERs to address local flexibility and transmission grid congestions.

This approach allows identification of transmission flexibility needs through assessing system needs but simultaneously overlooking distribution grid needs and congestions, which leads to potential unavailability of the flexibility resources foreseen from TSO side.

Proposed implementation steps could help bring more attention to distribution level congestions:

— **Comprehensive National Flexibility Evaluation:** Conduct evaluations that integrate renewable energy, peak demand, and system reliability requirements to guide flexibility deployment. Translate these needs into specific targets and actions for distribution grid operators. Create incentive structures for DSOs to invest in flexibility resources and infrastructure that align with national grid needs.

— **Guidelines for Distribution Grids:** Provide clear guidelines and directives to DSOs for the implementation of flexibility resources at the local level. Establish performance standards and monitoring mechanisms to ensure compliance and effectiveness. Use performance-based regulation to encourage innovation and efficiency in flexibility services at the local level.

— **Coordination Mechanisms:** Establish a coordination body or platform to facilitate communication between the TSO and DSOs. Provide technical and financial support to DSOs for the necessary upgrades and implementations.

3.5.3 Hybrid Flexibility Assessment Approach - DSO–TSO Integrated needs approach

The hybrid approach integrates both top-down and bottom-up techniques and captures the impact of local flexibility resources on the larger grid. Since information are flowing both directions from TSO to DSO and vice versa, hybrid model could compensate for the limitations of other two approaches. While hybrid grid modelling can provide a comprehensive view, it may be resource-intensive and require significant computational power and significant amount of diversity of localized data, grid automation and control at both TSO and DSO level.

Additional implementation considerations for Hybrid approach to complement bottom-up and top-down approaches:

- **Integrated Model Development:** Develop integrated models that combine top-down planning with bottom-up resource data to capture interactions and dependencies. Use these models to simulate scenarios and assess the collective impact of local and national flexibility resources.
- **Bidirectional Information Flow:** Establish data sharing protocols and real-time communications between stakeholders, including DER owners, aggregators, and TSOs (Uzum et al., 2024). Establish two-way communication channels between the TSO and DSOs to share data, forecasts, and operational decisions.
- **Collaborative Flexibility Management:** Enable DSOs to provide input into national flexibility strategies based on local insights and capabilities. Create collaborative platforms where TSOs and DSOs can jointly manage flexibility resources and coordinate actions. Activation of flexibility by one SO should not harm the grid operation of the other SO (Hillberg et al., 2019).

4 Conclusions

The European Electricity Market Design reform and the introduction of National Flexibility Assessments underline the importance of addressing flexibility at every grid level. In order to meet the EU's climate and energy targets, the grid must be capable of incorporating a growing share of variable renewable energy while maintaining stable and secure supply.

This report examines the essential elements for assessing flexibility needs focused on distribution systems. DSOs' role in flexibility provision in managing resources such as distributed generation, energy storage, and demand-side management, among others is highlighted. The increasing adoption of elements of flexibility at distribution grids call for coordination between DSOs and TSOs to assess local flexibility needs with the broader requirements of the transmission system.

Three approaches for TSO and DSO coordination have been explored. The hybrid approach, integrating both top-down and bottom-up methodologies, provides a robust framework for addressing both local and national flexibility demands. However, implementing these strategies requires overcoming other challenges. Technical barriers, such as the need for standardized communication protocols, interoperability between systems, and advanced forecasting capabilities, should be taken into account to enable integration of DERs into flexibility markets.

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List of abbreviations and definitions

Abbreviations	Definitions
ACER	Agency for the Cooperation of Energy Regulators
AMI	Advanced Metering Infrastructure
BESS	Battery energy storage systems
CAISO	California Independent System Operator
DA	Distribution Automation
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DFS	Demand Flexibility Service
DSM	Demand-side management
EMD	European Market Design
EV	Electric vehicles
FNA	Flexibility Needs Assessment
GOPACS	Grid Operator Platform for Active Congestion Management
JRC	Joint Research Centre
PV	Photovoltaic
RES	Renewable Energy Sources
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant

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