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Conclusions and recommendations

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Executive summary

ALEXANDER, **A**ccelerating **L**ow voltag**E** fle**X**ibility p**A**rticipation i**N** a gri**D** saf**E** manner, provides a comprehensive framework to remove barriers that could block the full potential of the use of flexibility available in the low voltage (LV) network for the provision of system services (both long-term, as important source to guarantee security of supply, and short-term, as provider for balancing services).

The flexibility challenge and ALEXANDER's solutions

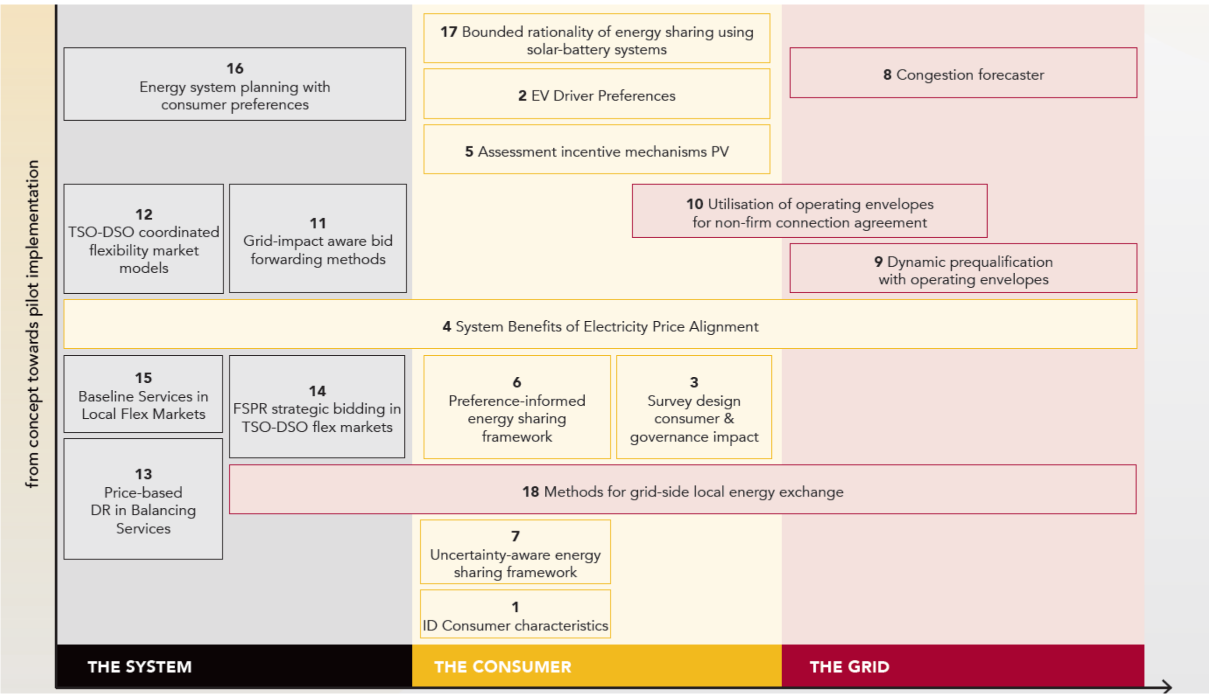
The first chapter introduces the growing need for flexibility in electricity systems. As renewable energy expands and electrification accelerates, power flows become increasingly variable and harder to manage. Traditional approaches that rely on centralised control or passive consumers can no longer guarantee system stability or security. Flexibility — the ability of the electricity system to adjust to the variability of generation and consumption patterns and to the grid availability, across relevant market timeframes — has therefore become a cornerstone of the energy transition. However, in order to ensure sufficient flexibility levels, it is important that flexibility from assets connected at the LV-grid, are also mobilized.

Today, the participation of LV flexibility is still limited due to the existence of several technical, operational, organisational, social and financial barriers. Products for system services are, for example, not available for or adapted to the requirements of LV flexibility providers. Moreover, challenges arise to ensure a secure grid operation at all voltage levels in case of procurement and activation of flexibility for system services close-to-real time. Furthermore, the heterogeneous nature of end-user preferences and decision processes is insufficiently understood, hence, not considered in the assessment of the potential of LV flexibility (adequacy) on the one hand and the design of flexibility services and mechanisms on the other hand (for operational purposes). The potential of demand response for flexibility provision has been widely examined at a technical level, but consumers were almost exclusively modelled as being rational and homogeneous, which is not necessarily in line with real consumer behaviour. This means that, although technically feasible, potential service providers may not react to market signals according to the postulates of economic rationality as expected under the assumptions of rational behaviour. Similarly, in the context of state-of-the-art adequacy assessments, the availability of LV flexibility and uptake of behind-the-meter PV and storage is based on assumptions. Again, this flexibility and DER investments may not materialize if the proper, user-centric incentives are not available.

To accelerate the participation of LV flexibility as a provider of system services in the future, the ALEXANDER project will address several key research questions to remove existing barriers and unlock the true value of LV flexibility for the Belgian system. In doing so, ALEXANDER focusses on solutions in three key pillars:

- The **consumer** pillar, showing how individual and collective non-rational consumer behaviour, preferences, and trust determine whether flexibility is offered in practice.
- The **grid** pillar, providing tools that enable DSOs to manage flexibility safely and cost-effectively even with limited observability.
- The **system** pillar, analyses implications of the previous pillar-solutions and of emerging individual and collective behaviours of LV users on the Belgian system balancing and adequacy.

In total, and as visualized in the figure below, ALEXANDER develops **18 key exploitable results** (KERs) that tackle challenge in these three areas. These are explained in detail in Annex A.



By integrating these views, ALEXANDER explored in depth different fundamental innovations, and links these to concrete local actions. As such, the project demonstrates how combining behavioural insights, operational safety, and regulatory coherence can unlock new flexibility resources and help Belgium prepare for an increasingly decentralised energy future.

Key lessons learned: The five dimensions of flexibility

Accounting for the **consumer**, **grid** and **system** perspective, ALEXANDER found that project learnings could be categorized into five interdependent dimensions that together define how low voltage participation in a grid safe manner can be accelerated:

- **Flexibility potential** – How much flexibility is effectively available (that is: the flexibility potential) is influenced by a number of important factors. First of all, there is the technical capacity (e.g. number of assets per LV-consumer) that influences the theoretical potential. This theoretical potential is further influenced by differences between consumers in terms of preferences, characteristics and behaviour. And finally, there is the market and regulatory potential that can put restrictions on or positive incentives towards the available flexibility.
- **Flexibility mechanisms** – Both implicit incentives (e.g. dynamic grid tariffs, flexible connection agreements, incentives for grid-safe P2P trading) and explicit mechanisms (e.g. TSO and DSO flexibility markets) must be designed to align consumer motivation with grid safety and operational reliability.
- **Flexibility tools** – (Distribution) System operators need accurate operational tools to 1) forecast congestion and increase grid visibility, 2) facilitate flexibility procurement and activation in a cost-efficient, grid safe and coordinated way when the TSO is procuring, 3) but also when multiple system operators (both DSO and TSO) are procuring.
- **Flexibility value** – When procuring flexibility, SOs need to make a trade-off between grid investments and the use of flexibility. On the other hand, the end-user (the flexibility provider) also wants to be compensated with a minimum value for its offered flexibility to recuperate its investments and potential discomfort. As a result, shared valuation methods are essential to align the perspectives of consumers, DSOs, TSOs, and aggregators, ensuring that all actors see a fair return on their participation.
- **Governance: coordination, roles, and data** – Real progress depends on integrated governance, coordination processes, clearly defined roles, including the respective

responsibilities, transparent information-sharing, and trust-building between technical, market, and social domains.

These lessons emphasise that the acceleration of low voltage flexibility participation in a grid safe manner as an important provider of long-and short term system services is not the responsibility of a single actor or technology — it is a shared system capability that must be enabled through actional solutions like the ALEXANDER KERs.

Conclusions and recommendations: From insights to action

The recommendations are structured around five action domains that together determine the success of flexibility implementation: **regulation, incentives, communication and knowledge sharing, tooling and infrastructure, and future research and development.** These dimensions reflect both the technical and institutional logic of flexibility—linking the rules that govern it, the signals that activate it, the understanding that sustains it, and the infrastructure that enables it.

Regulation - Policy and transition planning: A coherent policy and governance framework is essential.

Regional differences in market maturity and regulation threatens the scalability of flexibility. A national flexibility roadmap should coordinate regional approaches while allowing for contextual diversity. This includes clear milestones, standardised data protocols, and harmonised DSO–TSO coordination rules. Furthermore, policymakers should adopt a uniform valuation methodology for flexibility to ensure that economic, technical, and social benefits are assessed consistently across regions and actors. Grid safety remains the DSO's responsibility, even when flexibility is activated by others — governance structures must therefore empower DSOs with the authority, tools, and data access needed to manage flexibility securely. Coherence is also required between implicit mechanisms (like tariffs) and explicit market-based services so that they reinforce each other. Finally, fairness and transparency must underpin all flexibility governance to maintain public trust and equitable access.

Incentives - Understanding the LV-grid consumer: Consumers are the foundation of flexibility.

Effective participation depends on understanding consumer diversity, risk preferences, and motivations, and on developing appropriate tools and business models for both individual and collective end consumers while using this knowledge on consumer diversity. Policies should move beyond "average" assumptions to tailor incentives by segment, ensuring inclusivity and accessibility. Flexibility should be reframed as a trusted, consumer-centric service that offers visible value—such as comfort, autonomy, and savings—rather than as a technical constraint. Stable, pre-announced policy roadmaps are crucial to maintain trust and prevent the uncertainty that has hampered past transitions. Incentives must be harmonised across distributed energy resources (DERs) so that investments in PV, batteries, and EVs complement each other rather than compete. Markets should enable safe value stacking, allowing participants to access multiple services without duplicating risks or complexity.

Communication and knowledge sharing - Communication and collaboration are enablers of trust and coordination.

Belgium's multi-regional setup, combined with the multi-actor involvement of different energy players, demands structured mechanisms for knowledge sharing and collective learning. Belgium has multiple stakeholder and working groups set-up to do so (Synergrid, FORBEG and other stakeholder WGs, 'Stroomgroep Flexibiliteit'…). These should be further reinforced to strengthen stakeholder dialogue within the different knowledge sharing mechanisms and WGs. This will help Belgium to move from operational discussions to the design of common visions on where and when to do what and how. Continuous communication is vital—both to educate consumers and to align stakeholders (e.g. vision and regulation across regions, market implementation and flexibility procurement…). Information sharing, clear roles, and predictable policy sequencing reinforce stability, and will help to bridge the gap between technical, behavioural, and economic expertise.

Tooling and infrastructure - Infrastructure and digital readiness turn ambition into action.
Flexibility cannot scale without investment in digital and physical infrastructure. Observability, real-time data access, and interoperability are the operational foundations for managing distributed flexibility. Integrated IT/OT systems, common data exchange standards, and secure, role-based access frameworks are required to coordinate TSO–DSO–FSP actions. Policymakers should prioritise investment in measurement infrastructure, forecasting tools, and local congestion management capabilities. Ensuring equitable access—through digital inclusion, EV charging infrastructure, and access to different types of flexible assets—is equally vital to avoid socio-economic exclusion.

Future research and development - Continuous research and innovation must remain integral.
Flexibility evolves with technology, behaviour, and market design. The roadmap calls for a permanent research–policy interface, where pilot projects, behavioural observations, and model updates inform regulatory decisions. Real-world testing, iterative feedback, and integration of behavioural realism into system models are critical to ensure that flexibility frameworks remain adaptive, fair, and evidence-based.

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Abbreviations and acronyms

aFRR	Automatic Frequency Restoration Reserves
API	Application Programming Interface
BRP	Balance Responsible Party
CM	Community manager
D	(ALEXANDER) Deliverable
DCE	Discrete choice experiment
DER	Distributed Energy Resource
DSO	Distribution system operator
EV	Electric vehicle
FCR	Frequency Containment Reserves
FSP	Flexibility Service Provider
GDPR	General Data Protection Regulation
HP	Heat pump
HV	High voltage
ICT	Information and Communication Technology
IT	Information technology
KER	Key Exploitable Result
LV	Low voltage
MV	Medium voltage
NFCA	Non-firm connection agreement
NFS	Network Flexibility Study
OE	Operating Envelope
OPF	Optimal power flow
OT	Operational Technology
PQ	Prequalification
PV	Photovoltaic
RSF	Residual supply function
TRL	Technology Readiness Level
TSO	Transmission system operator
WG	Working Group

Terminology list

- **DCE**: A Discrete Choice Experiment (DCE) is a research method used to understand people's preferences by presenting them with different hypothetical options (choices) that vary in specific characteristics. By analysing the choices people make, researchers can estimate the relative importance of each characteristic and predict how people might respond to new alternatives or policy changes.
- **NFCA**: 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. 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-parties, such as aggregators or FSPs, access to network data (Liu, Ochoa, Wong, & Theunissen, 2022).
- **Grid prequalification**: Method to ensure that the FSPs' service delivery does not endanger the reliability of other grids. PQ can be both static or dynamic.
- **Static PQ**: In Belgium, today, grid prequalification is currently done via a network feasibility study, which provides static flexibility capacity limits for distributed flexibility resources. This study usually considers a close to worst-case scenario, rendering potentially conservative limits. Furthermore, the study is typically conducted infrequently, implying that the limits might not always be appropriate since the operating points of distribution grids at the moment vary highly throughout the day and are getting closer to their physical limits. On the other hand, the direct inclusion of distributed grid constraints into the market-clearing problem can render the problem intractable, as a network representation of a distribution system is typically highly complex. Furthermore, it can also reduce market transparency, as the clearing no longer depends only on a merit order.
- **Dynamic PQ**: Compared to static grid PQ, in case of dynamic grid PQ, the impacted SO assess potential grid constraints closer to actual procurement, implying that the assessment is repeated more frequently (e.g. day-ahead or intraday). As such, dynamic PQ accounts for the dynamically changing state of the grid. Multiple methods to implement dynamic grid PQ have been performed, among which the operating envelope (OE) approach which calculates grid-safe limits of all flexibility resources.
- **Network representation**: In terms of grid prequalification, grid constraints need to be accounted for. This can be done in multiple ways. Either advance network models can be used, which are very accurate, but also very data and computationally intensive. Alternatively, a more simplified network model can be used which linearised power flow equations. This method is more simplified than the advanced network model, yet still requires accurate network data. As sharing of network data can be sensitive, two alternative network representations are the sensitivity / impact factor model and the market areas based on network representation approach. For these two last methods, no grid data are needed. Impact factor models model how grid variables are affected by the change in power of flexibility resources, while a market area is an area in which the resources need to be located as indicated a priori (for instance based on postal codes, proximity to a specific grid element, etcetera…).
- **Bid aggregation mechanism**: Apart from grid prequalification, in KER 11, ALEXANDER also developed two other grid safety measures for distributed-level flexibility market participation and activation (as part of bid forwarding tools), namely ex-post correction and bid aggregation mechanisms. In the bid aggregation mechanism, the 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. Then, the 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. Each DSO thus locally determines how much flexibility it can safely offer, based on its own grid constraints, and submits a simplified, aggregated bid curve called a Residual Supply Function (RSF) to the TSO. The TSO then includes these RSFs in its market clearing, ensuring that if any of those are cleared, local issues will not occur. 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 show that this method can approach the performance of a fully integrated (common) market with a full network representation.

- **Ex-post correction mechanism**: Besides preventing the occurrence of local grid issues through prequalification, an ex-post correction market mechanism can be utilized to resolve local grid issues at a certain cost if feasible. 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 ran 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.

1 Introduction

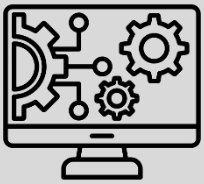
1.1 The challenge

Europe’s electricity systems are being pushed to their limits. As electrification deepens across sectors, system operators face a mounting challenge: how to ensure reliable operation under tighter constraints and rising uncertainty. Transmission and distribution grid investments are ramping up, but with an estimated €584 billion investment needed for physical upgrades alone, they cannot reasonably close the gap between supply and demand [1]. Increasingly, the flexibility of demand itself is becoming a critical resource. More specifically, engagement of the growing number of flexible assets connected to the low-voltage (LV) network—such as electric vehicles (EV), rooftop PV, home batteries, and heat pumps (HP) —must be mobilized to provide their flexibility in ways that support mid-voltage (MV) grid operations and market balancing for high-voltage (HV) grids.

Elia’s latest Adequacy and Flexibility Study (2026–2036) provides a stark warning [2]. It projects that by 2026, flexibility needs may not be met for around 300 hours per year—a number that could double by 2036 if battery adoption and end-user flexibility are not scaled up. These shortages are not only due to lack of installed capacity, but also due to insufficient mechanisms to engage that capacity when and where it is needed. The study estimates that for Belgium an additional 1.8 GW of consumer and decentralized PV flexibility will be required by 2026, rising to 2.5 GW by 2030. Much of this flexibility is theoretically available at the LV level but will only contribute to MV-/ and HV- level balancing and congestion services if effective engagement and coordination mechanisms are put in place.

The ALEXANDER project is grounded in this challenge. Rather than focusing on local LV grid management, it explores how residential and prosumer assets connected at the LV level can participate in flexibility services at all grid levels, including balancing and congestion management. This pivot to demand-side resources is essential but far from straightforward. The challenge lies not in the availability of flexible devices, but in how these distributed assets are integrated and activated for use in MV and HV flexibility markets and system services. Overcoming barriers at the **consumer**, **grid**, and **system** levels is critical to accomplishing this goal:

Barriers at consumer, grid and system level	
Consumer	Unlocking flexibility at scale begins with understanding who consumers are and what constrains their decisions. Most planning models still treat users as homogenous and fully rational, ignoring critical behavioural factors such as risk aversion, trust, digital literacy, and complex household routines. The real-world participation needed depends not only on economic incentives but also on comfort, autonomy, and perceived fairness. Flexibility is rarely a priority for households and will not be reliably delivered unless it is made simple, trustworthy, and clearly valuable. Price signals and program offerings must be framed to align with household values, yet current mechanisms often assume users will respond predictably to dynamic tariffs or platform-based incentives. Without addressing this behavioural heterogeneity, flexibility forecasts risk being inaccurate and system incentives poorly targeted.
	DSOs are increasingly expected to support system-wide flexibility through the coordination of residential and prosumer assets. However, until smart meters are fully rolled out, LV networks remain relatively unobservable and insufficiently instrumented for this task. DSOs face limitations in identifying congestion risk, forecasting usage, and determining where and when flexibility is needed. Furthermore, even when flexibility is technically

Grid	available, current tools often lack the granularity or reliability to ensure safe activation. Many LV networks are unbalanced, and phase-level visibility is often unavailable. Coordination is further complicated by regional regulatory differences and fragmented ICT systems. Forecasting tools, headroom calculations, and activation processes need to operate within the bounds of this uncertainty and with partial data, while also being compatible with market processes and deployable within existing operational structures.
 **System**	At the system level, flexibility from LV assets presents both an opportunity and a challenge. While these resources can contribute to adequacy and balancing, their integration into MV-level services raises new multi-grid coordination and reliability concerns. Markets currently lack mechanisms to align DSO and TSO needs, creating risks of double activation, congestion, and inefficient dispatch. Flexible resources may be technically capable but become unavailable due to conflicting activations or lack of grid-awareness in market-clearing processes. Additionally, real-time system management depends on timely and accurate forecasts, yet behavioural variability and low observability make this difficult. Regulatory frameworks and market platforms have not kept pace with the operational complexity of managing distributed flexibility at scale, leading to underuse of flexibility, inefficiencies, or exposure to new risks.

Europe's **regulatory framework** increasingly emphasizes the integration of DER and active consumer participation in flexibility markets. Furthermore, DSOs and TSOs are expected to coordinate more closely, ensuring that small-scale assets can contribute to system-level services safely and efficiently [3]. However, translating high-level EU directives into national practice is complex. Reliable LV asset participation in MV-level flexibility markets requires clear rules around prequalification, activation, and settlement—supported by real-time data and digital coordination tools. Digitalization is critical, but not sufficient on its own. Data must be embedded in tools that are operationally usable, scalable, and robust to consumer heterogeneity and local grid conditions.

On top of all these challenges, Belgium's unique and diverse environment complicates the current challenges even further. The three regions operate under distinct energy regulations, naturally leading to differing procedures for enabling LV flexibility. While Synergrid facilitates alignment across the regions through shared documents like MG FLEX, C8/01, and a model DSO-FSP contract, regional regulators (VREG, CWaPE, BRUGEL) apply these inconsistently due to the unique challenges each region faces [4]. For instance, regulations and guidelines surrounding EV charging stations providing flexibility face different challenges in the urban environment of Brussels where most chargers are publicly shared by apartment buildings and businesses, compared to Flanders and Wallonia where privately-owned, residential chargers are more common.

In Flanders, the regulatory framework allows all consumers to offer flexibility services, individually or through aggregation, under non-discriminatory rules, with DSOs responsible for managing access, data exchange, and market processes [5]. The VREG oversees these processes through the TRDE, requiring DSOs to implement standardized procedures, model contracts, and transparent communication to support end-user participation and ensure efficient flexibility integration at the distribution level [6]. There is a strong emphasis on trading-off procurement of flexibility services and grid investments, as such not allowing flexible connection agreements

(VREG, 2022). Flexibility is one of the spearheads of the Flemish energy- and climate plan (VEKP) [7] and is discussed in detail in the Flemish Flexibility plan 2025 [8]. The Flemish DSO, Fluvius, implemented two pilot local flexibility markets (one of active power, one for reactive power) and is as such actively exploring market-based flexibility procurement. These markets are, as of writing of this report, the only local flexibility markets operated by a DSO in Belgium. Finally, Flanders implemented a capacity-based grid tariff to capture flexibility.

In Wallonia, on the other hand, from 2026 ToU tariffs with different colours (green, orange, red) will be implemented to incentive consumers to behave flexibly. In addition, the region is working on different types of connection regimes with flexible access for production and storage units. In attendance, ORES is already launching a product on non-fixed connection agreements for new connections at MV. Generally, in Wallonia, flexibility provision requires each access point to undergo DSO-led prequalification, including a grid impact study, with all specifications subject to approval by the regulator CWaPE. DSOs may impose restrictions, apply dynamic qualification procedures, and manage flexibility registers, making end-user participation in flexibility services highly conditional on grid capacity, local risks, and formal regulatory compliance [9]. Finally, like Flanders, ORES is setting up a local flexibility market at MV-level.

In Brussels, the distribution system operator Sibelga has expressed reservations regarding the development of commercial flexibility (Sibelga, 2024). As such, Brussels is currently not opting for the implementation of a local flexibility market or commercial flexibility in general. Instead, Brussels focusses on connection agreements, rule-based approaches and grid tariffs. Specifically, for EVs, the DSO is allowed to limit the charging/discharging capacity of EVs (Art 2.30) (Sibelga, 2024). In terms of grid tariffs, Brussels is foreseeing a progressive evolution of the share of the capacity tariff in the total grid fees (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.

Despite harmonization efforts, regional divergences in legal mandates and perspectives on flexibility complicate uniform access for LV assets, creating operational and legal uncertainty for aggregators and market actors attempting to scale participation across regions.[1] Part of these differences are further strengthened by the different geo-socio-economic situation in the different regions. Brussels is characterized by an urban environment with more international and energy-poor population, living in multi-household and collective buildings with less ownership (more renting). Flanders on the other hand has a mix of urban and rural environments, yet still comparatively densely populated compared to the Walloon rural and forest environments. These leads to differences in investments in public versus private EV charging, and investments in HPs and PV. Across all regions, however, one trend is clear: the contribution of flexibility assets to system needs is growing, but not fast enough.

[1] For further information regarding the regulatory structures of Flanders, Wallonia, and Brussels, refer to Section 2.1 in ALEXANDER Deliverable 3.2 [10].

1.2 ALEXANDER's solutions

Resolving barriers to increasing LV-flexibility potential is the focus of the ALEXANDER project. In order to accelerate the participation of low voltage flexibility as important provider of long-and short-term system services, ALEXANDER will propose solutions to remove technical, operational, social and market barriers. An in depth understanding of the heterogeneous nature of consumer behaviour will form the basis of new concepts for adequacy modelling and flexibility provision. ALEXANDER accomplishes this in the following way:

ALEXANDER's solutions to increase LV-flexibility participation	
Consumer	ALEXANDER replaces simplified behavioural assumptions with evidence-based models that reflect real-world consumer diversity. By capturing factors like risk perception, trust, and preference heterogeneity through discrete choice experiments, the project improves forecasts of household participation and supports incentive designs that align with actual user motivations and constraints.
Grid	ALEXANDER equips DSOs with tools for safe activation of LV flexibility in MV and HV services, including data-sparse congestion forecasting, grid-aware flexibility headroom calculations, and dynamic prequalification. These are designed to work with limited observability and align with operational platforms, ensuring practical, scalable deployment across Belgium's regional contexts.
System	ALEXANDER supports integration of LV flexibility through coordinated market models, risk-aware activation, and trust-based pricing mechanisms. It addresses challenges such as strategic bidding and conflicting grid priorities, enabling more reliable and efficient use of distributed assets in MV-level balancing and congestion services.

As electrification accelerates and volatility increases, the failure to activate LV assets will lead to higher system costs, more frequent imbalances, and lost opportunities for consumers to benefit from the transition. Policymakers and system operators must move quickly to align incentives, develop the necessary tools, and adapt regulatory frameworks to support this cross-level integration.

The remainder of this report synthesizes the key findings of the ALEXANDER project and presents actionable recommendations for stakeholders. It begins with a summary table (Table 1) of the project's Key Exploitable Results (KERs). The annex provides the full description of each KER. The following chapter takes the core triple perspective that ALEXANDER used to develop the solutions and expands them into an interwoven matrix of lessons that connect the consumer, the grid, and the system with the flexibility potential, mechanisms, tools, value, and enabling conditions required to achieve the goal of highlighting what is required to turn this theoretical potential into operational reality.

Table 1: Overview of the ALEXANDER KERs. KERs are coloured based on the perspective they primarily offer a solution for: Consumer (yellow), Grid (red), and System (black).

KER	Title	Problem	ALEXANDER Solution	Owner(s)	Links
1	*Identification of consumer characteristics to unlock low voltage flexibility*	Current models assume consumers are homogeneous and rational, which misrepresents real behaviour and risks overestimating the practical flexibility available from distributed energy resources.	A literature review defined a use case framework and identified key behavioural, technical, and contextual factors (grouped as intrinsic, extrinsic, and routine-related) that influence residential flexibility adoption beyond traditional economic incentives.	VITO	D2.1 [11] [12]
2	*Driver Preferences for Investment in Flexible Electric Vehicle Charging*	Unmanaged EV charging could strain the grid during peak hours, but flexibility depends on user participation. Assuming uniform adoption without accounting for preferences risks overestimating the true potential of EV flexibility.	Discrete choice experiments (DCEs) reveal that Belgian EV users prioritize upfront costs, are influenced by future pricing expectations, and face barriers like range anxiety. Preferences for smart features suggest what user elements are important to further increase flexibility potential.	UA UHasselt	D2.2 [13]
3	*Survey design to analyse the influence of individual consumer characteristics and governance approaches on their engagement in collective flexibility concepts*	Energy communities (ECs) face recruitment and retention challenges due to limited understanding of how governance structures affect consumer engagement. Financial and technical incentives alone cannot explain or drive sustained participation in these collective energy systems.	A survey and DCE framework were developed to examine how governance elements (such as transparency, decision-making, and benefit-sharing) shape consumer participation in ECs, providing tools to assess and improve engagement strategies beyond economic incentives.	UA UHasselt	D2.3 [14]
4	*System-wide benefits of temporal alignment of wholesale–retail electricity prices*	High temporal granularity in electricity pricing can improve system alignment but demands complex household participation. It remains unclear whether simpler pricing structures offer sufficient system benefits and flexibility while still incentivizing adoption of PV and batteries.	Simulation results show that three- or six-hourly pricing captures most flexibility benefits with less complexity than real-time pricing. However, volumetric and capacity tariffs weaken price signals, reducing household responsiveness and overall system efficiency.	KU Leuven	D2.4 [15]

5	*Assessing the impact of financial benefits on household PV adoption in Belgium*	Meeting Belgium's 2030 renewable targets requires greater household adoption of PV, but uncertainty around future financial benefits, especially under dynamic pricing and reduced incentives, limits investment, particularly among low-income municipalities.	Historical analysis shows households respond strongly to pre-announced incentives and prefer output- or capacity-based rewards over net metering. Increasing clarity and certainty of benefits can significantly improve PV adoption, especially in underserved communities.	KU Leuven	D2.4 [16]
6	*A Preference-Informed Energy Sharing Framework for a Renewable Energy Community*	Energy communities in Belgium currently use a single, fixed internal pricing rule, ignoring diverse member preferences. This limits satisfaction and efficiency, as socio-economic, environmental, and equity-based values are not reflected in energy allocation.	ALEXANDER developed a framework combining preference elicitation, product differentiation, bilevel optimization, and an innovative pricing mechanism. This enables community managers to tailor energy exchanges and pricing to member preferences, improving engagement and system performance.	UMons	D2.4 [17]
7	*On the limited observability of energy community members: An uncertainty-aware near-optimal bilevel programming approach*	Traditional energy community models assume fully rational behaviour, but real users operate under bounded rationality, face unclear price signals, and deal with PV intermittency, leading to inefficiencies, volatility, and perceived unfairness in energy sharing.	ALEXANDER introduces an uncertainty-aware energy sharing framework using stochastic and bilevel optimization. It models real consumer behaviour, accounts for limited price visibility, and guides decisions through improved internal pricing aligned with solar variability and user constraints.	UMons	D2.4 [18]
8	*Congestion forecast*	Low observability in LV networks limits DSOs' ability to forecast grid conditions or identify congestion risks, preventing effective asset management and flexibility procurement, and ultimately hindering cost-efficient, proactive distribution grid operation.	ALEXANDER's LV congestion forecasting tool estimates congestion risks on distribution feeders using probabilistic methods based on historical load data, connection profiles, and weather forecasts, enabling DSOs to anticipate constraints without full real-time monitoring.	VITO	D3.1 [19]
9	*Dynamic grid prequalification /qualification using operating envelopes*	Balancing markets often activate flexibility resources without considering distribution grid constraints, risking local congestion and voltage issues, especially as low-voltage resources grow in potential	ALEXANDER's grid pre-qualification tool calculates dynamic, grid-safe operating envelopes for MV distribution-level flexibility resources, ensuring their market activation does	VITO	D3.2 [10] [20]

		due to increasing electrification across consumer segments.	not compromise local network reliability by solving tailored optimal power flow problems.		
10	*Utilisation of Operating Envelopes in Non-Firm Connection Agreements (NFCAs)*	Non-Firm Connection Agreements help prevent LV congestion but may block pre-qualified flexible assets from market participation, creating tension between local grid protection and system-level service delivery, ultimately undermining efficiency and trust.	ALEXANDER provides a method using relaxed three-phase unbalanced optimal power flow to calculate safe, day-ahead flexibility limits per user, enabling dynamic NFCAs that balance grid safety with reliable access to flexibility markets.	ULB VITO	D.3.2 [21]
11	*Grid-impact aware bid forwarding methods/tools*	Belgium's emerging local flexibility markets create coordination challenges between DSOs and TSOs, where unaligned bid forwarding risks unsafe dispatch, double activations, and inefficiencies, limiting the system-wide value and trust in distributed flexibility.	ALEXANDER develops three grid-aware bid forwarding methods (ex-post correction, prequalification, and bid aggregation) to ensure multi-market bids from distributed assets are safely activated without violating transmission or distribution grid constraints.	VITO	D3.3 [22]
12	*Simulation environment for the comparison between different TSO-DSO coordinated flexibility market models*	Overlapping participation in DSO local flexibility and Elia's balancing markets can cause conflicting activations and grid issues. Without coordination, market actions may undermine one another, risking inefficiencies, grid instability, or wasted flexibility.	ALEXANDER provides a simulation environment to test and compare TSO–DSO coordination schemes using real network and bid data, enabling evaluation of market performance, grid impacts, and activation outcomes under various design configurations.	VITO	D3.3 [23] [22]
13	*Price-Based Demand Response Participation in Balancing Services: A Value-Oriented Multi-Scenario Inverse Optimization Framework*	Real-time pricing aims to activate residential demand response, but unpredictable consumer reactions expose aggregators to delivery risks and lost revenues. Without modelling behavioural uncertainty, RTP can destabilize grids and weaken the viability of flexibility markets.	ALEXANDER introduces a data-driven framework that learns consumer price-response patterns and embeds uncertainty into aggregator decision-making, enabling more reliable demand response activation, reducing financial risk, and strengthening residential flexibility contributions to grid stability.	UMons	D4.1
14	*Simulation environment for analysing the likelihood and impact of FSP strategic*	Emerging local flexibility markets are vulnerable to strategic bidding, where FSPs manipulate prices or capacity to	ALEXANDER models FSP behaviour in TSO-DSO coordinated markets using Stackelberg game theory, capturing strategic, bounded-rational	VITO	D4.1

	bidding in TSO-DSO coordinated flexibility markets	maximize profits. This distorts dispatch, inflates costs, and risks conflict between local and system-level grid needs.	bidding. This enables analysis of efficiency losses, market distortions, and the design of safeguards against market power abuse.		
15	*A Framework for Heterogenous Energy Communities Providing Baseline Services in Local Flexibility Markets*	Belgium's growing DER adoption stresses LV grids, yet current flexibility models neglect energy community diversity and user motivations. Citizen-led energy trading needs coordination mechanisms that align household preferences with grid constraints and regulatory goals.	ALEXANDER offers a grid-aware local flexibility market framework for energy communities, combining dynamic user-centric pricing, realistic household models, robust baselining, and fair Shapley-based revenue sharing to ensure reliable DSO coordination and equitable flexibility participation.	UMons VITO	D4.1
16	*Energy system planning with consumer preference for low voltage flexibility in the context of Belgium*	As renewable integration and EV uptake accelerate, energy system models risk misjudging flexibility potential by overlooking consumer willingness to adopt smart charging, potentially leading to reliability gaps or inflated system costs.	ALEXANDER links DCEs with energy system planning models to quantify EV flexibility adoption, testing remuneration sufficiency and enabling future integration of consumer preferences directly into long-term system design for greater accuracy.	KU Leuven VITO UHasselt	D4.2
17	*Bounded rationality of energy sharing using solar-battery systems*	Estimating residential solar-battery flexibility is hindered by diverse, non-rational household behaviours. Ignoring risk perception, trust, and control preferences leads to inflated flexibility forecasts and poorly targeted incentives.	ALEXANDER applied DCEs with cumulative prospect theory to identify risk preferences and trust dynamics, producing realistic participation estimates and actionable insights for consumer-centric tariff design and flexibility program development.	UA UHasselt	D2.2 [13]
18	*Methods for grid-safe local energy exchange (peer-to-peer trading)*	Peer-to-peer energy trading increases local injections and offtakes, altering grid flows and flexibility needs. Without safeguards, these shifts can compromise grid safety, making it vital to assess and manage P2P impacts on distribution networks.	ALEXANDER introduces methods to quantify P2P trade impacts on grid operations and proposes DSO control strategies, preventive blocking and corrective incentives ensuring grid-safe trading while preserving efficiency, flexibility cost control, and regulatory coherence.	VITO	D2.4 [24]

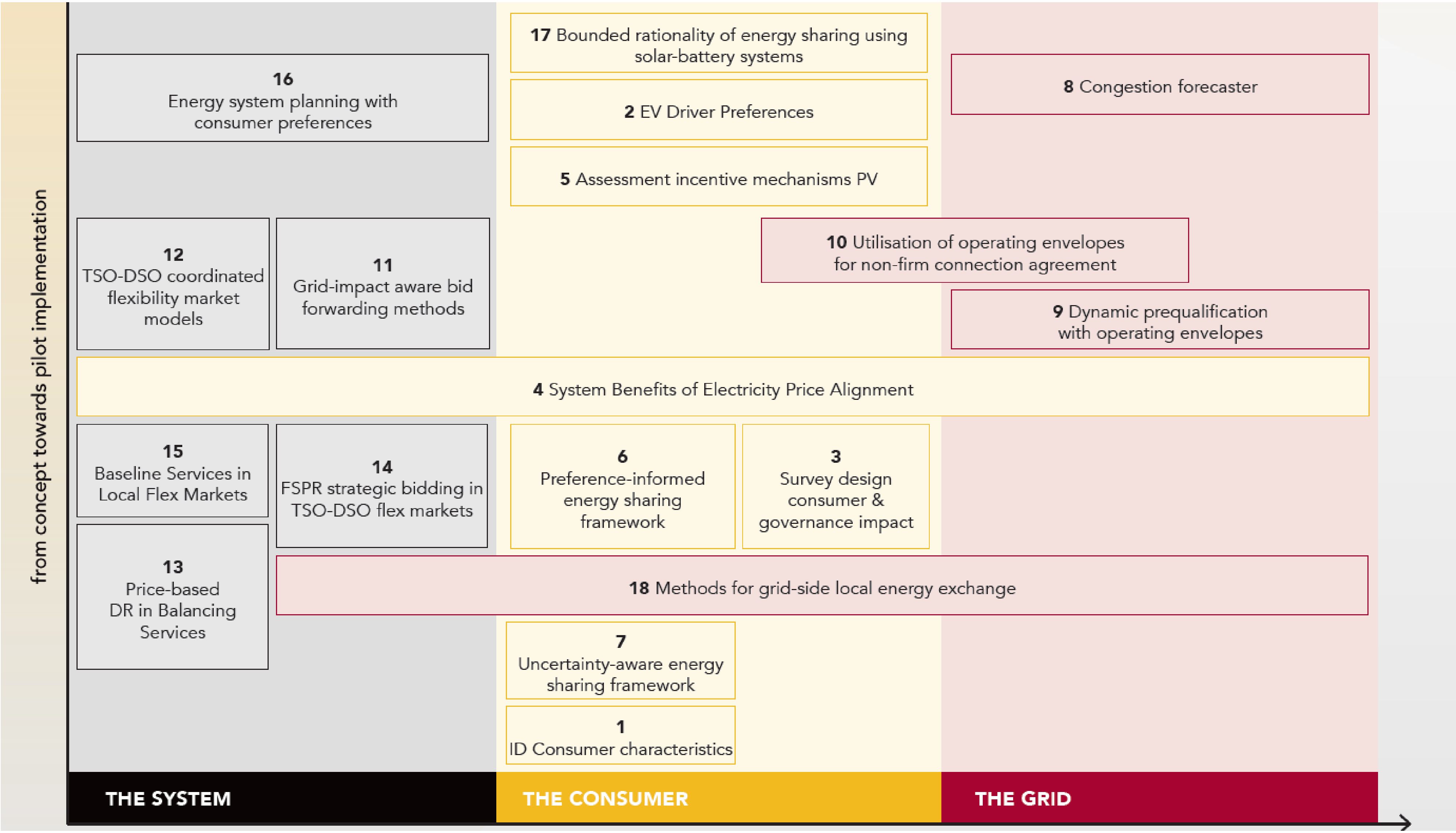


Figure 1-1: Overview of the ALEXANDER Key Exploitable Results

2 Key Lessons learned

From the start, ALEXANDER focused on understanding and removing the technical, behavioural, operational, and economic barriers that prevent the widespread use of LV flexibility for system services. The project was structured around three key perspectives— **consumer**, **grid**, and **system** — reflecting the belief that unlocking flexibility at scale requires insights and solutions that span the entire energy ecosystem.

While this framing has proven useful for addressing the roles and challenges specific to each actor, it does not fully capture the functional dynamics of flexibility itself. In this chapter, we reframe the discussion by placing flexibility back at the centre of the analysis. Drawing on the full breadth of the project's findings, we organize our key learnings into five interdependent dimensions: Flexibility Potential, Flexibility Mechanisms, Flexibility Tools, Flexibility Value, and Enabling Conditions. These reflect what it takes to make LV flexibility work in practice, technically, economically, and socially. Rather than being tied to any single perspective, they span all three, offering a more integrated and operational view of how flexibility is activated, coordinated, and valued. We briefly introduce each of these dimensions below before turning to the specific lessons learned. The links between the different dimensions are also highlighted in Figure 2-1: The five dimensions of LV flexibility are discussed in more detail below:

1. **Flexibility Potential**
   Flexibility begins with understanding what is available. This category examines how the potential for flexibility is determined by household technologies, and how it is influenced by user preferences, behaviours, and willingness to adapt energy use.

2. **Flexibility Mechanisms**
   Unlocking flexibility requires mechanisms that connect users to the system. These include both explicit schemes like flexibility markets, and implicit ones like dynamic tariffs and flexible connection agreements. Mechanisms must incentivize participation while also ensuring that system operators can depend on the flexibility being delivered.

3. **Flexibility Tools**
   System operators can only use flexibility if they know when and where it is needed. (Distribution) System operators need accurate operational tools to 1) forecast congestion and increase grid visibility, 2) facilitate flexibility procurement and activation in a cost-efficient, grid safe and coordinated way when the TSO is procuring, 3) but also when multiple system operators (both DSO and TSO) are procuring.

4. **Flexibility Value**
   Flexibility must be priced appropriately to ensure that it is used efficiently. This category explores how to match consumer compensation with the system's willingness to pay, ensuring that financial incentives reflect both user motivation and system value—key for scaling up flexibility services.

5. **Governance: coordination, roles, and data**
   Real progress depends on integrated governance, coordination processes, clearly defined roles, including the respective responsibilities, transparent information-sharing, and trust-building between technical, market, and social domains.

By organizing our final learnings along these five thematic axes, we reflect the reality that making LV flexibility accessible and usable is not the responsibility of one actor or domain—it is a shared, systemic challenge. The learnings presented in the following sections are designed to support that shared mission, and to ensure that LV flexibility becomes an integral part of a secure, affordable, and sustainable energy system.

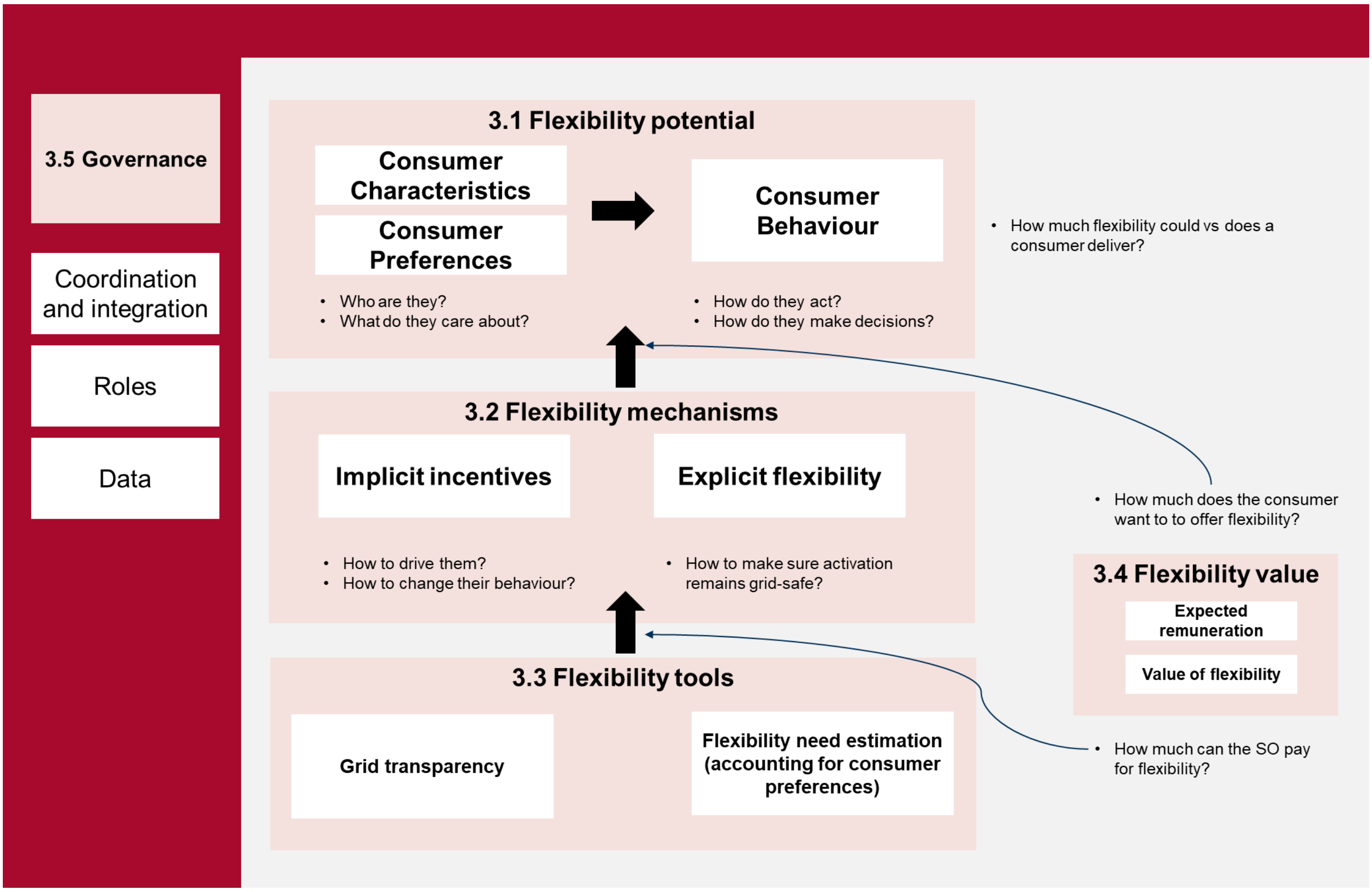


Figure 2-1: The five dimensions of LV flexibility

2.1 Flexibility potential

Understanding a consumer's flexibility potential is crucial for system planning, efficient grid operation, and maintaining grid stability. This potential depends not just on available technologies, but also on what consumers are willing and able to do. Preferences (such as valuing comfort over savings), consumer characteristics (such as whether they indeed own flexible devices) and behaviours (like ignoring real-time price signals), directly impact how and when flexibility can be offered. Without accounting for these human factors, adequacy and flexibility models risk overestimating available flexibility and policies may fail to gain traction. Recognising this complexity is key to unlocking reliable, user-driven flexibility at scale. In this section, we zoom into how consumer preferences, consumer characteristics and consumer behaviour influence flexibility potential.

2.1.1 Consumer preferences

A key challenge in designing effective policies and solutions, especially in complex areas like LV flexibility, is understanding who the consumers really are and what drives their behaviour. There is no single, uniform "consumer": people differ widely in their preferences, shaped by diverse backgrounds, values, and emotional responses such as anxiety or confidence. These underlying traits, like prioritizing comfort over cost or expressing environmental concern, are often hidden but play a crucial role in shaping decisions. Without accounting for these variations, interventions risk missing the mark. The challenge, then, lies in identifying and responding to these nuanced preferences to create strategies that resonate with different consumer types.

It is important to highlight that most of the existing research on DER adoption tends to examine technologies in isolation, focusing separately on EVs, PV, HPs, home batteries, or smart appliances. This fragmented approach misses important synergies, shared adoption patterns, and strategic opportunities that emerge only when technologies are studied in relation to one another.

Through KERs 1, 2, 4, 5 & 6, ALEXANDER captured the following insights on consumer preferences:

- Which factors shape consumer preferences?
- What is the role of financial preferences?
- How does risk-aversity shape preferences?
- How do trust and information shape preferences?

Which factors shape preferences?

DER adoption and flexibility provision are shaped by both intrinsic (personal values, attitudes, perceptions…) and extrinsic (infrastructure, regulation…) factors—but intrinsic ones are often more decisive and more likely to overlap for certain technologies

User-centric, intrinsically driven factors are essential for effective DER adoption and voluntary engagement

KER 1 highlights that while external drivers like subsidies, regulations, and infrastructure are important, intrinsic factors—rooted in individual psychology and behaviour—frequently carry greater weight in influencing DER adoption decisions or influencing the decision to provide flexibility. These include a person's values (e.g., environmental concern, desire for autonomy), attitudes toward the technology, social norms within their community, perceptions of control, and prior experiences with similar systems. The decision to adopt is often not purely rational or financial but shaped by how the technology fits into one's identity and worldview. For instance, people who strongly identify as environmentally conscious are more likely to adopt solar PV or EVs, even when financial incentives are modest. Similarly, users motivated by CO_2 reduction, or social factors such as setting an example for children, are more willing to shift their energy use without needing large financial incentives. More details can be found in [12].

Bundling DER technologies with shared adoption drivers can accelerate uptake

KER 1 finds that some DER technologies share similar intrinsic adoption factors, such as positive attitudes, strong environmental values, high awareness, and motivation to adopt. This overlap presents a clear opportunity to promote these technologies as bundles, rather than in isolation. PV and home batteries are a prime example. Both attract users who are environmentally conscious, value energy independence, and are willing to invest in long-term savings. KER 1 highlights that these technologies are already being marketed together in some countries, reinforcing their natural synergy. More details can be found in [12].

What is the role of financial preferences?

Consumers are more likely to invest in flexibility-enabling technologies when they perceive clear, immediate financial benefits and have confidence in the stability of future prices or in the actors providing the service.

Consumers heavily discount future benefits, requiring upfront rewards or guaranteed returns to adopt flexibility-enabling technologies

KER 2 and KER 5 reveal that a major barrier to the adoption of flexible technologies, such as electric vehicle smart chargers or rooftop PV, lies in how consumers perceive and value future financial gains. KER 2 shows that consumers apply a very high implicit discount rate (IDR) of around 28.5% when evaluating flexibility-enabling technologies such as smart EV chargers; far above typical market interest rates of 4–5%. This "flexibility discount rate gap" indicates that users heavily undervalue long-term savings in favour of avoiding upfront costs, making adoption unlikely without clear and immediate benefits. KER 5 complements this by demonstrating, in the context of PV adoption, that incentive schemes offering guaranteed, upfront euro-denominated returns (such as output- or capacity-based payments) are more effective than net metering, which delays financial gains. Together, the findings highlight that for both flexibility and PV investments, consumers respond best to transparent, immediate value rather than deferred savings.

Strategic implementation of tariff and price structures can promote DER installations within households or specific energy products

As further discussed in section 2.3.1, the structure of tariffs and prices plays a decisive role in shaping which DERs households choose to install, thereby influencing the overall flexibility potential. KER 4 demonstrates that, at the residential level, the fixed tariff does not incentivize investments in DERs. In contrast, both the volumetric and capacity-based tariffs lead to significantly higher adoption. The volumetric tariff promotes larger investments in solar PV, with installed capacity increasing by roughly 80–100% compared to the fixed tariff case. Meanwhile, the capacity-based tariff results in the highest deployment of residential batteries, with installed capacities up to two to three times greater than under the volumetric tariff. This evidence highlights how targeted tariff design can be used as a policy lever to promote specific types of DERs and optimise flexibility outcomes and thus increase flexibility potential (Figure 2-2). In addition, KER 6, for instance, demonstrates an approach enabling community manager to differentiate and prioritize energy products (e.g., green energy from green supplier, local solar and battery storage, "grey" third-party energy) according to community members' socio-economic preferences, thereby increasing user satisfaction and engagement. Green and locally sourced electricity are priced according to an internal pricing mechanism designed for users who demonstrate a higher preference for these options. In contrast, users may transact grey electricity with the supplier at retail rates. In the practice, this meant that green and locally sourced electricity were priced slightly higher than conventional (grey) power due to differentiated internal pricing that reflects users' willingness to pay for environmental and social value. In the case study, green electricity purchased from an external supplier was about 10% more expensive than grey electricity. Thus, members with stronger preferences for green or local energy pay marginally more per kilowatt-hour, but the difference remains modest, on the order of a few euro cents and contributes to measurable benefits such as approximately 3.3 kg CO_2 emission savings in the simulation.

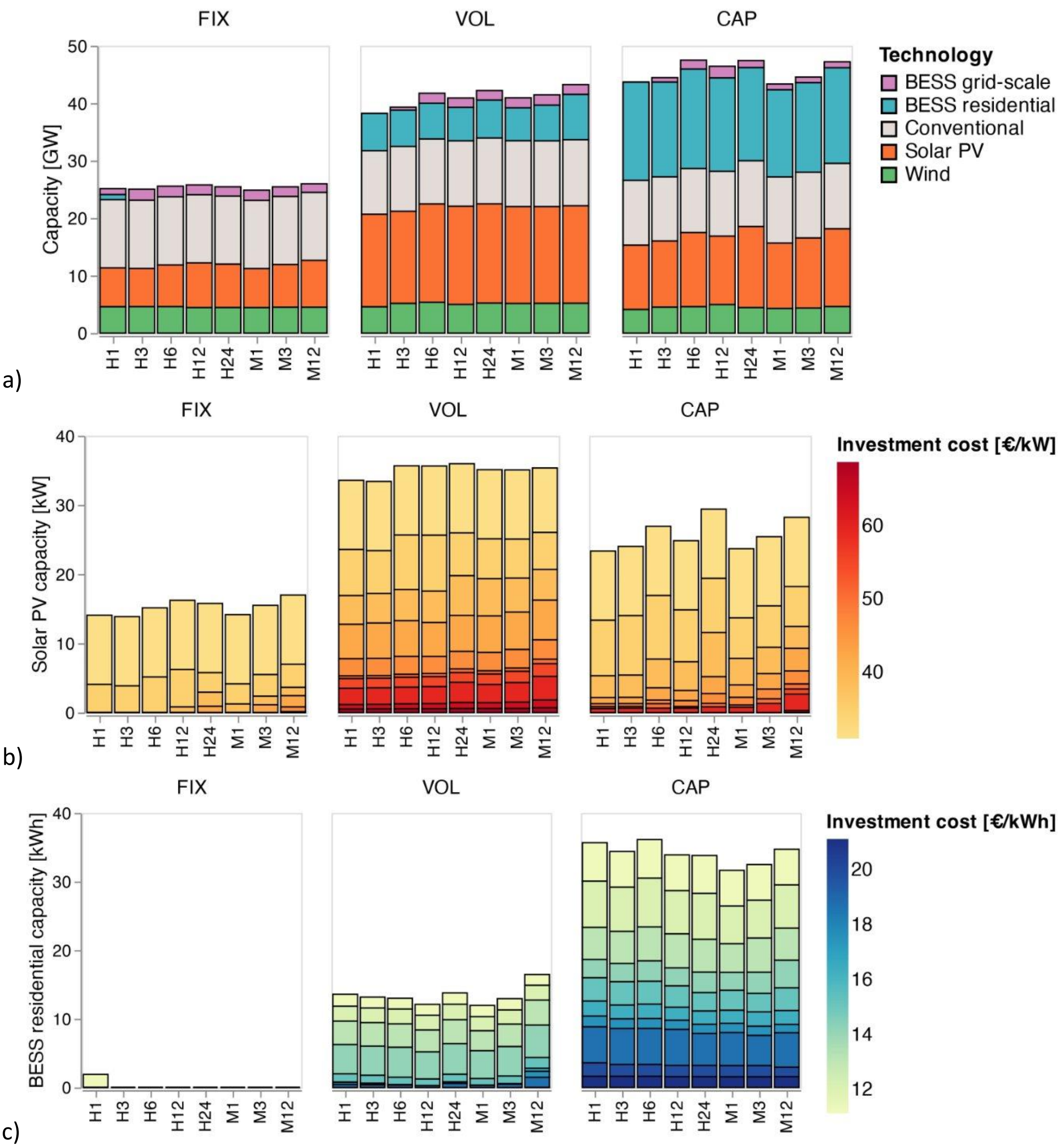


Figure 2-2: Changes in adoption of PV and BESS by households under different retail price granularities and tariff structures a) generation capacity investments by technology, b) PV capacity investments, and c) BESS capacity investments. Abbreviations are FIX: fixed tariff, VOL: volumetric tariff, CAP: capacity tariff, H: hourly temporal granularity, M: monthly temporal granularity

Future price expectations and trust in energy providers increase willingness to invest in flexibility
KER 2 demonstrates that users who anticipate rising electricity costs, particularly through time-of-use tariffs or higher per-kWh rates, are more inclined to adopt flexibility-enabling technologies such as smart EV chargers. These expectations appear to strengthen perceived value in flexibility and justify upfront investment. Furthermore, respondents with higher trust in their energy retailer are significantly more willing to upgrade their chargers to smart chargers and exhibit a lower implicit discount rate (23%) compared to the average. This is also one of the reasons why in KER 6,7 and 15, an important role is given to the energy community manager as an interface between different external

actors. This indicates that trust reduces perceived uncertainty and investment risk, reinforcing the importance of credible, transparent communication from providers.

How does risk-aversity shape preferences?

Users are more likely to engage in flexibility behaviours when technologies are (perceived) familiar, convenient, and allow them to retain control over their energy use.

Technology-specific concerns—especially range anxiety and control loss—limit flexibility adoption, but targeted service features can mitigate these barriers

KER 1 finds that technology-specific concerns, such as range anxiety for electric vehicles and safety fears around battery storage, act as critical barriers to both the adoption and the use of DERs for flexibility. In the case of EVs, users often avoid off-peak charging due to fear of running out of battery, choosing instead to fully charge regardless of price signals. These concerns reduce the willingness to engage in flexibility behaviours even after adoption. KER 2 builds on this by showing that range anxiety is significantly associated with reduced uptake of flexible EV chargers, particularly among drivers with longer commutes. However, KER 2 also demonstrates that these barriers can be addressed through smart charging service agreements that include features such as guaranteed minimum battery levels, portable power banks, and privacy protections. These features not only increase willingness to participate in managed charging programs but also reduce the compensation needed to ensure participation. Furthermore, while loss of control is a concern, KER 2 shows that 54% of users are willing to relinquish control. Together, these findings indicate that while DER-specific usability concerns inhibit flexibility provision, well-designed service offerings can meaningfully reduce perceived risks and support broader adoption.

Perceived comfort, convenience and familiarity strongly influence flexibility behaviours

KER 1 shows that minimizing discomfort is critical for users to adopt flexibility. For example, users with low thermal tolerance are less likely to accept smart control of heat pumps, which pre-heat during off-peak hours. Reluctance to compromise on comfort is a major inhibitor, especially in load-shifting applications involving heating and cooling. In addition, KER 1 shows that households with greater experience or familiarity with smart technologies are more likely to provide flexibility. For instance, users accustomed to real-time energy monitoring were more comfortable making temporary adjustments during price peaks. KER 2 shows that familiarity with EVs is positively associated with a willingness to adopt flexible charger features. This suggests that experience reduces uncertainty and improves comfort with flexibility-enhancing technologies.

Perceived control over energy use increases flexibility participation

In line with the previous sub-learning, KER 1 also finds that users who feel in control of their appliances and DERs (e.g., being able to override automation) are more willing to join load-shifting programs. Lack of perceived control, especially in automated or remote systems, can induce anxiety and resistance.

How do trust and information shape preferences?

Building and sustaining consumer trust through credible policies, transparent communication, and targeted awareness is essential to close knowledge gaps, reduce perceived risks, and ensure long-term adoption of DERs and flexibility services.

Policy sequencing and credibility are essential for sustained adoption.
Historical PV adoption patterns (KER 5) show that sudden changes in support schemes, especially without adequate notice, lead to volatile and reactionary consumer behaviour. This not only undermines the effectiveness of incentive programs but also erodes public trust as consumers are not certain about the continuation of certain benefits (KER 1 and KER 2). To ensure long-term credibility, all policy adjustments, whether phase-outs or redesigns, should follow a transparent, pre-announced roadmap with sufficient lead time for consumers and markets to adapt.

Institutional trust is a precondition for activating residential flexibility.
Findings from the EV smart charging study (KER 2) reveal that willingness to delegate control over charging decisions to third parties is strongly influenced by trust in those actors—particularly energy retailers and aggregators. Trust in energy retailers is a decisive factor in whether consumers participate in flexibility schemes such as managed EV charging. When users are asked to give up control over charging schedules, they must have confidence in the entity managing their flexibility. This insight suggests that regulatory efforts to promote flexibility must also include provisions to monitor, ensure, and communicate institutional trustworthiness. Consistent with our solar-battery experiment (KER 17), households similarly preferred delegating control to established intermediaries such as retailers and system operators, underscoring that institutional trust and regulatory oversight are prerequisites for effective aggregation across distributed energy technologies. Without trusted intermediaries, even well-designed market mechanisms are likely to underperform in the residential sector.

Awareness and knowledge gaps significantly limit consumer engagement.
Clear, trusted, and accessible communication is essential to drive DER adoption and flexibility provision. KER 1 shows that understandable information, transparent tariffs, and trusted messengers significantly increase willingness to participate, while KER 2 highlights that targeted communication and service guarantees—such as minimum EV battery levels, portable power access, and privacy protections—can mitigate range anxiety and unlock EV flexibility. KER 5 further demonstrates that making benefits more salient and certain can close adoption gaps in low-income municipalities. Across technologies, low awareness and technical misunderstandings persist as key barriers, underscoring the need for clear, relatable messaging and hands-on guidance at critical decision points.

2.1.2 Consumer segmentation and characteristics

While understanding consumer preferences helps explain why people choose to engage in flexibility, understanding consumer characteristics and segments explains who is most likely to participate and under what conditions. People differ not only in motivation but also in access, knowledge, and capacity to act. Age, education level, household routines, income, home ownership, and existing technology use all influence both the ability and willingness to adopt flexibility-enabling solutions. Importantly, these factors often matter more than location or gender. For example, younger users and users with solar panels are more likely to value and adopt flexible EV charging, while older users with longer commutes are less responsive to such features. At the same time, low-income communities may show lower adoption rates not only due to affordability, but also due to higher risk aversion and lower access to information. These findings highlight that universal policies may fail to reach or engage key segments, and that targeting the right users with tailored messages, incentives, and support can lead to greater uptake at lower cost. In this section, we examine how flexibility is shaped by socio-demographic characteristics, technological access, and consumer segmentation.

ALEXANDER, through KERs 1, 2, & 5, addresses the following question regarding the unique characteristics that shape consumer preferences and behaviour:

- How can social, economic, and contextual factors be addressed to improve equitable and effective participation in the energy transition?

How can social, economic, and contextual factors be addressed to improve equitable and effective participation in the energy transition?

Tackling financial, informational, and situational barriers—while focusing efforts on the most receptive consumer groups—can boost fairness and efficiency in DER and flexibility adoption.

Socioeconomic inequality in energy transition reflects differences in risk tolerance, not just affordability.
While financial constraints play a role, lower uptake of PV systems in low-income municipalities (as shown by KER 5), even when incentives are equivalent, indicates that adoption disparities are also driven by higher perceived risk, lower access to information, and a reduced ability to navigate uncertainty. Addressing this requires more than income-based subsidies. Policies must actively reduce complexity and cognitive burden for vulnerable groups, ensuring equitable participation in the energy transition.

Extrinsic factors vary significantly across DER types and flexibility provision
KER 1 finds that while intrinsic factors (e.g., attitudes, values, awareness, and behavioural intentions) show relatively consistent influence across DER technologies like EVs, PVs and home batteries (HBs), extrinsic factors vary considerably depending on the specific technology and its broader context. These external variables include infrastructure availability, ownership status, education, and market conditions, all of which shape how users engage with each technology. For example,

- **Ownership** plays a major role in determining whether someone can adopt rooftop PV or heat pumps, with renters often excluded from adoption due to legal or practical constraints. This highlights a key difference between Brussels Capital Region and the Walloon and Flemish region. In addition, according to Statbel, 55.8% of the Brussels households do not own a car, probably due to the urban nature of the region [25]. Compared to the rest of Belgium, only 26.9 % of the households doesn't have a car. Obviously, the decision to provide flexibility is also highly impacted by ownership of a smart meter, solar PV, or battery storage. However, trust in the technology and the system behind it is essential: ownership without trust may hinder usage.
- **Infrastructure** access is also highly technology-specific: EV adoption is strongly influenced by the availability and reliability of public charging networks, while home battery uptake depends on grid connection rules and local installation services. Flanders has significantly more charging stations than for instance Wallonia and Brussels [26].
- In the case of smart appliances, the technology's success is linked to the quality of internet **connectivity**, digital literacy, and compatibility with existing home systems—factors that vary significantly by region and demographic group. Glass fibre connection is for instance the highest in cities such as Brussels (57% of the households), or other regional centra like Brugge and Antwerp. However, most areas, especially in Wallonia, do not have a good Glass fibre connection [27]. Also, for mobile connections (4G and 5G) urban areas are generally doing better. Yet, especially Walloon rural regions have also in the case the least qualitative connections.
- KER 1 and 2 also show that **routines and households structures** limit flexibility potential. Routines, like work schedules or family obligations can constrain flexibility. Households with rigid schedules or dependents often avoid shifting appliance use. Flexibility is easier with non-time-critical tasks like laundry but concerns about convenience and noise remain. Similarly, KER 2 also shows that daily driving distance is negatively correlated with willingness to adopt a flexible charger,

suggesting that drivers with longer commutes are more reluctant to engage with flexibility features. Previous studies show that people in Brussels take the least time on average to get to and from work as they generally travel fewer kilometres [28]. However, exact travel distance differs even between provinces, which can lead to interregional differences. In Flanders, for instance, people living in East-Flanders have the longest commuting time (59 minutes) while people living in Flemish Brabant have the longest commuting distance (53 km).

- **Socio-demographic characteristics** such as age and education level are also proven to influence willingness to do investment in flexible chargers. KER 2 shows that 80% of the respondents are more willing to adapt of flexible charger. Generally, these respondents tend to be younger, and more highly educated. They are willing to do so for comparatively lower future energy bill savings to justify the upfront investment (compared to the other respondents). In contrast, older respondents are less likely to prefer flexibility, which may reflect greater concerns about range anxiety or unfamiliarity with managed charging systems. They were less responsive to energy-bill savings and showed little interest in flexibility. KER 5 shows that the adoption of PV/certain technologies is lower in low-income municipalities. In terms of age, statistics show that generally, the average age in the Brussels Capital City is lower than in other regions (37.6 years versus 41.7 and 43 years in respectively Wallonia and Flanders)[2]. In addition, on the other hand, energy poverty is the highest in Brussels.
- Furthermore, **policy and regulatory environments** impact DER adoption unevenly. Some countries or municipalities offer generous subsidies and streamlined permitting for PV, while others impose aesthetic or location-based restrictions.
- Likewise, **tariff structures and financial incentive schemes** differ across DER types, affecting their overall appeal and return on investment.

KER 1 highlights that these differences in extrinsic conditions lead to inconsistent adoption (but also flexibility provision) outcomes, even when intrinsic motivations are similar.

Targeted activation of responsive consumer segments offers greater efficiency than universal outreach.
Approximately 80% of surveyed EV users were receptive to adopting flexible charging technologies under the right conditions, whereas a smaller segment remained largely resistant (KER 2). This indicates that targeting policy interventions—such as incentives, education, and pilot programs—towards the most responsive consumer profiles can deliver substantial system value without requiring full population coverage. Policymakers are encouraged to adopt segmentation-based approaches in rollout strategies.

2.1.3 Consumer behaviour

This section focuses on how both individual and collective consumers, like members of energy communities, make decisions in response to various system signals and tools. Consumer behaviour is shaped by a range of factors, including bounded rationality, habitual routines, uncertainty, and differing sensitivity to real-time incentives or participative schemes. These behavioural traits influence how consumers respond to price signals, scheduling tools, or engagement mechanisms, directly impacting the effectiveness of models and policies that rely on their active participation.

In the context of Belgium's growing number of renewable energy communities and the increasing reliance on flexible LV users for local balancing, traditional models that assume fully rational, well-informed consumers often fall short. In reality, individuals and households make energy decisions based on incomplete information, limited attention, and simplified heuristics—conditions described by the concept of bounded rationality. This becomes especially important when dynamic internal pricing is used: users may misinterpret or overlook real-time price variations, leading to suboptimal or

[2] https://statbel.fgov.be/nl/themas/census/bevolking/leeftijd

unintended energy use. Such behavioural uncertainties, combined with the variability of technologies like solar PV, pose coordination challenges for both community managers and DSOs. Accurately understanding and incorporating consumer behaviour is therefore essential for designing effective, fair, and responsive energy systems.

ALEXANDER, through KERs 7 & 13, addresses the following regarding using insights on consumer behaviour:

- How can recognising the limits of consumer behaviour improve flexibility outcomes and coordination in energy systems?

How can recognising the limits of consumer behaviour improve flexibility outcomes and coordination in energy systems?

Incorporating bounded rationality into pricing and forecasting models makes flexibility schemes more reliable, resilient, and trusted by reflecting the actual ways consumers respond to signals

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Strategic integration of bounded rationality models can improve energy community coordination and flexibility outcomes

KER 7 addresses the shortcomings of current models that assume perfectly rational behaviour of consumers within markets. Strategic integration of bounded rationality models improves energy community coordination and flexibility outcomes by enabling internal pricing and resource allocation mechanisms that reflect real-world consumer behaviour more accurately. Standard economic models assume fully rational users with complete information, but in practice, energy community members respond based on partial price observability, limited decision-making capacity, and unpredictable local renewable generation. By explicitly modelling these behavioural constraints using stochastic bilevel programming, the proposed framework allows community managers to set internal electricity prices that account for consumer decision uncertainty while still optimizing for system-wide objectives such as peak load reduction and self-consumption. This leads to more reliable flexibility provision from energy communities, as internal pricing strategies and energy sharing rules remain robust even when members do not react perfectly to signals. The approach reduces dependency on external suppliers, improves grid coordination, and supports policy goals such as CO_2 reduction and decentralized energy participation. Importantly, integrating bounded rationality into operational decision models not only improves theoretical accuracy but also enhances trust and engagement among community members, who benefit from fairer, more transparent pricing and reduced exposure to unpredictable market dynamics. For more information, see [29].

Bounded rationality must be explicitly considered when forecasting consumer response to price signals.

In traditional demand response modelling, consumers are often assumed to react in a consistent and fully rational way to changing electricity prices. In reality, households face cognitive limits: they must make frequent, time-sensitive financial decisions without perfect information or analytical tools. This “bounded rationality” means that responses can vary greatly from day to day, even under identical price conditions. If such variability is ignored, forecast models risk overestimating the predictability of consumer behaviour, leading to inefficient pricing and misaligned market activations. By incorporating behavioural uncertainty into forecasting, KER 13 shows that it is possible to develop price signals that are more resilient to inconsistent responses, improving both operational stability and consumer trust in flexibility schemes.

2.2 Flexibility tools

As the energy transition accelerates, the demand for flexibility in LV networks is increasing — but with it, so does the risk of local congestion. Regulatory frameworks now push DSOs to make use of LV flexibility to address these challenges, rather than relying solely on costly grid reinforcements.

However, to activate flexibility safely and effectively, DSOs need to be able to forecast where and when congestion will arise and to derive precise control signals. This is not a trivial task. LV grids often lack detailed, real-time observability, and incomplete data on network topology, phase connections, or local loads can severely hamper efforts. Although HV and MV networks are already well equipped with advanced monitoring and control systems, LV networks remain largely unmonitored beyond the MV/LV substations. On top of that, incomplete knowledge about the LV grid — such as unclear network layouts, cable details, or phase connections at consumers — limits our ability to identify or anticipate technical challenges. Without this insight, activating flexibility on the LV level risks introducing new technical issues or operational constraints, rather than solving them. KER 8 was developed to tackle this challenge, combining smart metering data and other DSO system inputs to deliver reliable load and voltage predictions across the LV grid.

However, beyond the technical challenges, KER 2, 6, 16 and 18 reveal that user preferences and local energy exchanges also need to be accounted for to ensure more accurate grid need forecasts. Local energy exchanges, which lead to respective changes in injections and offtakes at different parts of the grid, have a direct impact on the grid status and hence on the grid's flexibility needs. Thus, accounting for such local interactions is essential to (i) quantifying the flexibility needs within the grid, and (ii) devising transparent, effective, and efficient (minimally restricting) methods for minimizing the risks of local trading on the grid. KER 18 was developed to address those challenges and quantified the impact that each P2P trade has on the power flows in the system, as such determining whether the P2P trade is harmful (cerates new congestions, or exacerbates existing ones) or helpful (reducing or eliminating congestions) to the grid.

We therefore focus on the following question:

- How to estimate and manage LV flexibility needs without full real-time grid visibility?
- Is there a risk of P2P trading and consumer preferences on flexibility need forecasts?

How to estimate and manage LV flex needs without full real-time grid visibility?

Probabilistic forecasting equips DSOs to manage flexibility-driven congestion in LV grids without requiring full grid observability.

Grid transparency can be significantly improved using probabilistic congestion forecasting tools, even with limited measurement data

KER 8 [30] demonstrates that DSOs can identify and manage congestion risks in LV networks through a statistical congestion forecaster, even without full real-time observability. KER 8 demonstrates a tool that estimates the probability of grid constraint violations—such as undervoltage, overvoltage, and overcurrent—on a node-by-node basis, enabling proactive management. Crucially, the tool does not require exhaustive real-time metering or knowledge of phase connections, lowering deployment barriers for DSOs. It outputs spatially and temporally resolved risk assessments, which can be used to flag high-risk areas and inform decisions on flexibility activation. KER 8 thus reveals that transparent grid monitoring is not contingent on costly measurement infrastructure but can be achieved through robust statistical modelling tailored to LV grid realities.

Activating flexibility without causing congestion requires a probabilistic understanding of how flexible assets impact the grid

KER 8 [30] also highlights that flexibility activation, particularly through residential batteries providing Frequency Containment Reserve (FCR), can induce significant congestion if not carefully managed. The deliverable presents a probabilistic impact analysis, where various battery deployment scenarios (from 5 to 45 units) are simulated using both historical and worst-case frequency signals. It finds that voltage congestion (undervoltage or overvoltage) occurs earlier and more frequently than current congestion due to the instantaneous nature of voltage violations versus the thermal inertia of current limits. Moreover, the spatial distribution of batteries, not just their number, critically affects outcomes. These insights are summarized in a comprehensive scenario matrix showing how increasing battery penetration shifts congestion likelihood from "unlikely" to "very likely." KER 8 demonstrates that flexibility needs cannot be evaluated deterministically; they must incorporate uncertainty, spatial variation, and the time dynamics of grid constraints.

Is there a risk of P2P trading and consumer preferences on flexibility need forecasts?

Both P2P trading and consumer preferences introduce uncertainty into flexibility need forecasts, making behavioural variability and local trade impacts central risks that DSOs must account for in grid planning.

Accurate grid planning requires combining technical optimisation with behavioural insights into flexibility adoption.

We learn that grid optimisation and investment planning cannot rely solely on technical assumptions about flexibility potential. KER 2 shows that user willingness to adopt flexibility features is uneven, shaped by factors such as age, education, trust, and perceived value. This highlights a key vulnerability: if DSOs and planners use uniform adoption assumptions, they risk misjudging available flexibility and misallocating resources. The findings further reveal that behavioural segmentation is central to understanding real flexibility potential. Data on income, trust, and consumer behaviour directly influence how DERs and flexibility services are taken up, leading to uneven impacts on local peak shifts and congestion patterns. This means that the grid's performance in practice reflects not only technical design but also social and behavioural drivers.

KER 6 builds a basic building block which enables to quantify the impact of LV users' preferences on providing flexibility to the system actors such as a DSO (e.g. for congestion management), as studied in KER 15. In other words, it consists in a first step to quantify local arbitrage and whether personal preferences of LV users, which may not be purely financial only, degrade (or not) their ability to reliably provide flexibility to an external actor such as a DSO. More specifically, KER 15 illustrates that user preferences and anticipated behaviours shape the pricing strategies applied within the community. Participants motivated by financial benefits receive more dynamic pricing schemes, whereas those driven by comfort considerations are offered less variable yet still competitive rates, aligning with their lower sensitivity to price fluctuations. The energy trading outcomes further reveal that user preferences influence both the volume and direction of electricity exchanges with the community manager and external suppliers. Economically motivated users focus on maximizing self-consumption and engage more actively in electricity sales. Moreover, preferences affect the flexibility potential of local resources, financially oriented communities provide the greatest upward and downward flexibility services, while comfort- and environment-oriented communities contribute less due to their operational limitations stemming from non-economic priorities.

KER 16 demonstrates the effect of integrating behavioural insights from KER 2 in traditional optimisation tools that manage EV charging demand, mitigate congestion and guide investment planning. Without these insights, the availability of flexibility provision by flexible EV chargers is overestimated. Yet, the results for both a direct and indirect integration of behavioural insights in energy system modelling show that the system has sufficient incentives to promote flexible EV chargers. While it is possible to use existing DCEs and energy system planning models, we recommend designing the survey and the energy system planning model at the same time for future studies.

Given adequate grid observability and awareness of potential P2P energy exchanges, the impact of local energy exchange on the grid can be quantified a priori.
KER 18 demonstrates that using power flow calculations, each pair of P2P trades can be translated into respective quantified modifications to different line flows, thus quantifying the impact that each P2P trade has on the grid and identifying whether such local trades exacerbate congestions. As such, these mechanisms support the flexibility needs estimation of the DSO as they allow accounting for local actions that can be taken by end-consumers and their associated grid impacts.

Unrestricted P2P trades do not need to be harmful, but the uncertainty they introduce require DSO to have control measures in place to minimize any potential risks.
KER 18 demonstrates that P2P trades when left completely free can at instances help reducing congestions and at instances lead to exacerbating them, where the two can also concurrently occur for different lines in the grid. This uncertainty then requires the DSO to have safeguards in place, i.e., control instruments which can be deployed, especially under stressed grid conditions to ensure that grid safety is preserved when enabling P2P trading. In this respect, grid-safe P2P trades are trades that do not lead to additional flexibility needs as compared to the originally estimated ones (i.e., without the occurrence of the P2P market).

2.3 Flexibility mechanisms

Another key element in obtaining flexibility, is understanding how flexibility can be mobilised. Two broad categories of flexibility have emerged: **explicit flexibility**, where resources are dispatched or traded as defined products in energy and ancillary service markets, and **implicit flexibility**, where end-users adjust their consumption autonomously in response to dynamic signals, typically prices or tariffs, without direct market participation. Each mechanism plays a distinct role across temporal and spatial dimensions of the system, and both have implications for market design, system operation, and regulatory frameworks. This chapter highlights the learnings for each of them.

2.3.1 Implicit consumer incentives

Implicit consumer incentives are financial triggers like energy prices and tariffs that influence how much consumers pay for their energy. Changes in these triggers can have a direct impact on their invoice and could therefore be an incentive to adapt their behaviour. We cover economic benefits of energy sharing and trading (through, for instance, allocation keys or P2P trading) also under this topic, as they influence a consumer energy invoice, resulting in a consumer's option to respond to these signals.

ALEXANDER, through KER1, KER2, KER4, KER5, KER6, KER13 & KER 18 addresses the following questions regarding aspects of financial consumer incentives that are relevant to activate consumers to contribute to LV flexibility:

- Do we need implicit consumer incentives?
- How to shape incentives to ensure they increase flexibility potential?

- How to shape incentives to ensure they ensure grid safety?

Do we need implicit consumer incentives?

Financial barriers remain the most consistent obstacle across all DER types: Consumers focus more on the immediate costs to buy an EV and a smart charger or to install PV than on future benefits delivered by smart charging and PV

Financial barriers hinder the adoption of DERs
Multiple ALEXANDER KERs (notably KER 1, KER 2, and KER 5) show that financial considerations are a decisive factor in consumer adoption of DERs, with KER 1 identifying high upfront costs, installation fees, and long or uncertain payback periods as persistent barriers. Evidence from KER 5 confirms that in Flanders and Wallonia, PV adoption patterns closely follow changes in incentive schemes, underscoring consumer sensitivity to financial benefits. However, KER 5 also finds that these incentives are less effective in lower-income municipalities, indicating that socio-economic constraints limit uptake, as explained in Section 2.1.2. Together, the KERs point to the need for well-designed, targeted incentives and financing models, combined with clear communication on long-term value, to overcome financial barriers and achieve higher adoption rates.

Consumer flexibility is not a given, but a policy-dependent outcome.
Evidence from both EV charging and PV adoption (KER 2 and KER 5) illustrates that consumer participation in flexibility schemes is not automatic or latent. Rather, it is shaped by how incentives are structured, communicated, and trusted. This highlights that residential flexibility must be treated as an output of intentional policy design, not as an assumed resource.

How to shape incentives to ensure they increase the flexibility potential?

To unlock household flexibility, energy models must go beyond cost optimization and reflect what users truly value—such as sustainability, locality, and fairness. In addition, incentives should be of high enough granularity, without becoming too complex.

Active participation fades over time without sustained incentives: continuous incentives are needed.
KER 1 finds that even among motivated users, flexibility engagement declines unless continuously supported. In studies from the Netherlands and Denmark, time-shifting of activities like laundry faded after initial enthusiasm, underscoring the need for long-term reinforcement strategies.

Effective future incentives will integrate <u>realistic behaviour modelling</u> with <u>consumer value preferences</u>, creating pricing that is both resilient to unpredictability and capable of motivating broader participation in grid flexibility.
KER 13 shows that traditional models assume consistent, rational reactions to price changes, but in practice, bounded rationality leads to unpredictable responses—especially when decisions are frequent and information is incomplete. Ignoring this variability risks misaligned price signals and inefficient market activations. Instead of relying on complex scenario-based stochastic models, which require large numbers of variables and high computational effort, KER 13 infers aggregate consumer price-response parameters directly from historical consumption and pricing data. In practice, this means that BRPs can send real-time prices to households with less computational overhead, improving scalability in large low-voltage networks. To this end, KER13 developed new data-driven frameworks that shift the forecasting objective from prediction accuracy to improving the quality of decisions made using those forecasts. This approach allows for the uncertainty in consumer responses to price signals

and their impact on the aggregator's decisions to be incorporated into the forecasting model selection process itself. In a proof-of-concept test case, the method reduced costly overactivation of demand response by up to 87% for downward balancing and 65% for upward balancing, while increasing BRP profits by more than 6% compared to a single-scenario traditional model focused solely on forecast accuracy.

KER 6 adds that pricing should also reflect consumer values such as environmental impact, local sourcing, or reliability. Simulation results from the Walloon case study confirm this: when user preferences were included, about 9% (11.08 kW of 122.44 kW) of total demand was met with green energy, cutting emissions by ≈3.3 kg CO_2 and increasing participation in local exchanges. Internal prices adjusted dynamically to these value-based choices, proving that tariffs reflecting user preferences can boost fairness and engagement. Together, these insights enable incentives that are both behaviourally resilient and value-informed, driving higher participation, fairer outcomes, and better coordination with DSOs to support grid stability.

The structure and timing of incentives are as important as their size.
KERs 2, 4, and 5 show that flexibility decisions (such as adopting smart chargers, home batteries, or PV) are strongly shaped by both the timing and design of incentives. In KER 2, drivers were more likely to invest in smart charging when anticipating time-of-use tariffs or rising electricity prices, while KER 5 finds PV uptake in Flanders and Wallonia spiked ahead of announced changes to incentive schemes, reflecting a preference for clear, guaranteed, and timely benefits. KER 4 further highlights that granular, time-varying tariffs enable more responsive energy use, and that tariff type matters:

- *Tariff type*: volumetric tariffs favour PV, while capacity-based tariffs better promote batteries. This is because capacity tariffs reward reductions in peak demand, making battery storage financially attractive for households seeking to manage consumption patterns. On the other hand, if there are only volumetric tariffs, which base charges on total consumption, rooftop PV adoption increases with modest rise in battery investments. These volumetric structures overemphasize solar generation without encouraging energy shifting or peak shaving, which are essential for effective flexibility. Overall, combining time-varying pricing with capacity-based tariffs strikes the most effective balance, supporting both battery and PV adoption and enhancing household contributions to system efficiency. Together, these findings stress that financial incentives must be well-timed, clearly framed, and matched to the technology to unlock consumer flexibility. Policy effectiveness is driven not just by the magnitude of support, but by how that support is perceived and understood by end users.
- *Granularity*: KER 4 explores how the design of retail electricity pricing affects household incentives for adopting and using PV and battery systems. While wholesale markets operate with fine-grained, hourly price variations, retail markets typically use flat or time-blocked tariffs, which limit the responsiveness of residential consumers by shielding them from the price fluctuations that would incentive grid-stable behaviour. Although real-time pricing can encourage active participation, it may also introduce bill volatility and complexity, discouraging adoption. KER 4 shows that aligning retail electricity prices in Belgium with wholesale market patterns using moderate temporal granularity can substantially reduce system costs by promoting more efficient household energy behaviours and investment in DERs but gains from real time pricing are not so significant in comparison to three- and six-hourly electricity pricing schedules for households. Section 2.4 zooms in in more detail on the exact value of this flexibility for the total Belgian energy system cost.

Trust, transparency, and simplicity are critical to successful preference-informed incentives
Designing effective incentives for DER adoption and flexibility participation requires more than technical optimisation; it depends on trust, transparency, and simplicity across all stages of engagement. KER 6 shows that integrating consumer values (such as environmental concern,

reliability, or locality) into pricing and energy-sharing schemes can expand participation and unlock new flexibility potential, especially when tariffs and products are clearly explained and reflect user priorities. However, as demonstrated in KERs 1, 2, 5, and 17 even the best-designed models will underperform if users do not trust the process, understand the tools, or believe their preferences will be respected. Complex models must therefore be paired with simple, user-friendly interfaces, transparent communication about how prices and allocations are determined, and credible, pre-announced policy roadmaps that give households and markets time to adapt. Trust in intermediaries, such as energy retailers or aggregators (KER 2), and confidence in the fairness and stability of incentives (KER 5) are prerequisites for sustained participation. When incentives are both preference-informed (KER 6) and transparently administered, they not only motivate cost-sensitive consumers but also engage those driven by identity, sustainability, and community benefit, broadening the flexibility base and improving coordination with DSOs.

How to shape incentives to ensure they ensure grid safety?

Unchecked P2P trading can introduce uncertainty to grid safety; however, with adequate control actions taken by the DSO, minimized limitations can be introduced to P2P trading to still leverage their advantages while safeguarding the grid, especially when operating in stressed conditions.

Subsidy and penalty mechanisms in the context of P2P trading can reduce risks of grid harm but may not always lead to grid-safe outcomes and face complexity and practicality challenges.

For the case of ensuring that incentives do not cause additional grid constraints, and/or that they ensure grid safety, ALEXANDER among others focuses specifically on the cases of incentives in case of energy sharing / P2P trade. In this case, KER 18 demonstrates that the application of penalties and subsidies to incentivize helpful P2P trades and disincentivize harmful ones can reduce the grid-associated risks of P2P trading and lead to relatively safer grid outcomes when compared to unchecked P2P trading settings. Nonetheless, such subsidies and penalties do not offer guarantees for achieving grid safety. In addition, such mechanisms suffer from two additional key drawbacks:

- The selection of the subsidy and penalty amounts: such selection must be fine-tuned to strike a balance so that it can, on the one hand, effectively incentivize helpful P2P trades and discourage harmful ones, while on the other hand making sure that the cumulative costs of such subsidies is minimized and fall below other corrective flexibility actions that the DSO could implement (e.g., sourcing flexibility from the local flexibility market). This finetuning exercise faces significant complexity and practicality challenges as it requires iterative steps to converge to adequate values.
- Regulatory challenges: The general application of such subsidy schemes interferes in the P2P market trades, which can lead to market distortions and discriminatory behaviour, and thus face regulatory obstacles.

Preventive blocking – whereby P2P trades are filtered out in case they pose grid-safety issues – is an easily implementable, regulation conforming, and grid-safe control instrument that the DSO can deploy to enable P2P trading while ensuring grid safety.

KER 18 also demonstrates that preventive P2P trades blocking mechanism, applied as a form of P2P trades prequalification filtering out harmful trades, can strongly support grid safety by preventively blocking trades from taking place that are identified to exacerbate congestions over critical lines or creating new ones. In this respect, the level of restriction to be applied is also controllable similar to a traffic light concept, whereby, under mild grid stress conditions, P2P trading can take place in a relatively unrestricted manner, while such blocking mechanisms are only introduced when stressed grid settings arise (e.g., high loading, high injection levels) and in a targeted way (considering a specific set of congested grid elements). Given the regulatory duty of the DSO to safeguard the grid, such method shows consistency with European regulatory frameworks.

These conclusions have been drawn based on a developed case study[3] in ALEXANDER. The original considered grid contained 2 congestions. Unconstrained P2P trading has resolved the original 2 congestions but created 12 new ones and has, thus, multiplied the local flexibility market costs by a factor of 19. These impacts motivate the need for DSO control instruments to constrain/guide P2P trading to safeguard the grid. The preventive blocking method has successfully prevented the creation of new congestions (2 congestions remain) and induced minor impact on the LFM cost and line loading, thus showcasing its ability to prevent P2P trading from worsening grid conditions. This comes at the cost of restricting possible P2P trades (P2P traded volume dropped by around 55% as compared to the unconstrained P2P trading option). However, this level of restrictions depends on the heavy grid loading conditions. For less stressed conditions, fewer P2P trades would be blocked. The penalty/subsidy method has prevented the occurrence of more congestions than in the case of unconstrained P2P (but still 12 congestion instances remain as compared to 2 under preventive blocking). The collective overflow over congested lines became more limited as compared to the base case, showcasing the impacts of the subsidy/penalty scheme and resulting in a decrease in LFM costs by around 50% as compared to unconstrained P2P. However, the cost remains around 10 times the cost under the preventive blocking method. The volume of P2P trades under the subsidy/penalty scheme was also comparable to that under the preventive blocking method.

Effective incentive design aligns user behaviour with grid stability and fair participation
Broader than merely looking at P2P trading, KER 15 demonstrates that effective incentive design is crucial to align user behaviour with grid stability goals. The framework shows that integrating preference-based pricing, anti-gaming baseline mechanisms, and fair reward sharing motivates users to offer genuine flexibility while discouraging strategic manipulation. By linking compensation to real contributions and respecting diverse user motivations, the approach builds trust, ensures equitable participation, and strengthens overall grid stability and safety.

2.3.2 (Grid-Safe) Explicit flexibility mechanisms

Explicit flexibility mechanisms cover a broad range of solutions, such as rule-based solutions, connection agreements, and market-based procurement solutions through which flexibility is procured through (local) flexibility markets. Under a market-based flexibility mechanism, an SO procures flexibility to meet its needs through a market. As resources of a flexibility service provider (FSP) participating in such a market can be located in a (LV) distribution system and a market-clearing mechanism, either for DSO-level or TSO-level markets, typically does not take into account a detailed grid representation, activating flexibility, particularly those located in distribution systems, might not be grid safe, i.e., it can cause local grid issues.

ALEXANDER focuses:

[3] The case study considered the Matpower 69-bus test system with increased loading conditions (to emulate stressed grid conditions and investigate the impacts of P2P trading and the proposed DSO control instruments), where the lines' average occupancy ratio is considered to be 65%, 60% of lines have occupancy ratio above 60%, and 2 lines are congested. A set of 172 P2P bids/trade offers are considered (originating from 46 nodes) where the prices are randomly drawn from a considered distribution and the quantities generated randomly based on the base injection/demand at the respective nodes where the peers are connected. A local flexibility market is in pace to procure flexibility for congestion management. The impact of the P2P trading (controlled or uncontrolled) on the grid, is measures via the number of congestions, their volumes (overflows), and the modifications to the cost of the LFM as compared to the case of no P2P market.

- On the one hand on **solutions** (KER 9, KER 10, KER 11) to ensure that activation of flexibility does not cause additional grid constraints or issues. There are different mechanisms that SOs can put in place to maintain the satisfaction of grid constraints. The timing of when these grid constraints are calculated and addressed plays an important role in their complexity and efficiency. It can be done 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 (as visualized in Figure 2-3)[4].

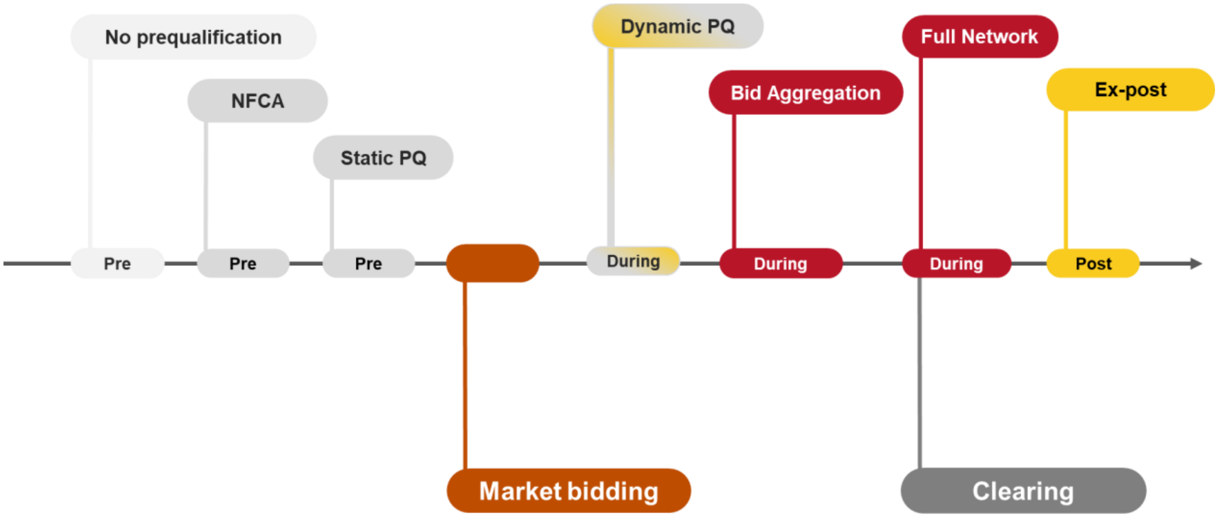

Figure 2-3: overview of grid-safety measure in relation to the timing of the bidding and clearing market phases.

- On the other hand, ALEXANDER also focuses on **elements that further impact market efficiency** and the choice of appropriate mitigation and/or prevention actions. For instance, KER 14 helps to understand how strategic bidding behaviour that FSPs may perform could impact market results.

ALEXANDER, through KER 9, KER 10, KER 11, and KER 14 addresses the following questions on the topic of explicit flexibility mechanisms:

- How can grid safety mechanisms be selected to balance efficiency, complexity, and market context?
- How can market design reduce the risk of strategic behaviour?
- How can a NFCAs be designed and implemented to balance grid safety, market commitments, effectiveness, and fairness?

[4] As a brief recap, the list of terminologies in the beginning of this report, summarises all the solutions, providing a quick overview of their purposes. Readers not familiar with the topic can check the list of terminologies or look at ALEXANDER D3.2 and 3.3 for more details.

How can grid safety mechanisms be selected to balance efficiency, complexity, and market context?

Preventive, context-specific grid safety mechanisms (such as prequalification, bid aggregation, or their combinations) offer varying trade-offs between efficiency, complexity, and feasibility, requiring choices aligned with market maturity, grid stress, and regulatory readiness.

Preventive grid safety measures before or during procurement are more effective than corrective ones

Preventive measures, such as static prequalification and NFCAs, taken before procurement, or dynamic prequalification and bid aggregation, taken during procurement, ensure better grid safety of activating distributed flexibility as compared to corrective measures, such as an ex-post market mechanism.

Relying on the latter does not reliably resolve grid issues, especially if the available flexibility resource is insufficient or in highly stressed grid conditions, as shown in KERs 11 and 12 [22], [23]. When this approach successfully solves the local issues, an extra operational cost is incurred, resulting in the loss of market efficiency, which can be around 20% in the simulated cases reported in [23].

On the other hand, bid aggregation allows the most efficient combinations of bids that are grid-safe at different aggregation levels to be considered in the market, resulting in close to optimal market results. This approach ensures grid-safe activation without requiring central access to DSO grid data. KERs 11 and 12 [23] show that bid aggregation nearly achieves the theoretically maximum efficiency. On the other hand, as compared to grid prequalification and ex-post correction, this mechanism is computationally much more complex, e.g., in the simulations reported in [23], the computational time required by bid aggregation is almost ten times longer than these other two methods. Nevertheless, it offers a realistic path forward for fragmented systems, replacing the need for full market integration while still enabling coordinated flexibility procurement. In this context, allowing DSOs to aggregate flexibility bids requires revisiting roles and regulations.

Finally, dynamic grid prequalification presents a compelling balance between computational complexity and operational effectiveness. While it does not achieve the same level of market efficiency as bid aggregation, it ensures grid safety and remains significantly simpler to implement. As demonstrated in D3.3 [23], the market inefficiency associated with dynamic grid prequalification can be up to an order of magnitude higher than that observed with bid aggregation, e.g., in one of the cases, the inefficiency of grid prequalification is 20% while that of bid aggregation is only 1.2%. However, this performance gap comes with a notable advantage: computational efficiency. For instance, simulations in D3.3 show that bid aggregation requires approximately ten times more computational time than grid prequalification for the same test cases. Given its lower complexity, and sufficient performance, dynamic grid prequalification emerges as a viable and pragmatic solution that effectively balances technical and operational demands.

Grid-specific analysis is essential—no one-size-fits-all for safety

Grid safety challenges vary significantly across urban, suburban, and rural distribution networks due to differences in topology, loading patterns, and technical constraints. For instance, urban grids often face thermal limitations due to dense infrastructure, while rural grids are more prone to voltage issues because of long feeder lines and uneven load distribution. D3.3 emphasizes that applying uniform safety measures across these diverse contexts (such as in Belgium) is ineffective. Instead, DSOs must conduct grid-specific, scenario-based analyses to identify the most appropriate mix of prequalification methods, operating limits, and flexibility mechanisms. This localized approach ensures both safe operation as well as effective and efficient use of available flexibility.

Prequalification is a critical tool—but method and timing matter

Having no grid prequalification risks serious grid safety issues when LV flexibility is activated without DSO oversight. Simulations in KER 9 show that markets operating under a model with no grid prequalification frequently cause grid issues, such as voltage limit violations or congestion on the distribution grid, i.e., up to 170% of line violations and 20% of voltage limit violations [23][5]. These violations might then require ex-post corrective actions from DSOs, driving up system-wide operational costs at best, and, in the worst case, compromising the operation of the grid. Proper prequalification methods are therefore recommended.

Static prequalification methods, such as the Network Flexibility Study (NFS) safeguard grid safety by blocking flexibility assets located in potentially constrained zones. However, they rely on conservative, worst-case assumptions, often excluding assets that could safely participate under actual grid conditions. Deliverable D3.3 [23] highlights that this approach, while simple, limits flexibility unnecessarily and reduces market liquidity. It recommends transitioning to dynamic prequalification using operating envelopes (OEs), which define asset-specific power limits based on real-time or forecasted grid conditions. This allows for more precise, situational control, enabling greater asset participation without compromising grid integrity. Though dynamic methods require better data and DSO capabilities, they are essential to unlock flexibility at scale and support efficient TSO-DSO coordination.

Dynamic grid prequalification near market-clearing improves grid-safe flexibility activation and reduces unnecessary restrictions, but requires high-quality data and system upgrades

KER 9 [10] shows that OE models applied close to market clearing enable more precise, real-time alignment between flexibility bids and actual grid conditions. Unlike static NFS, which impose coarse, long-duration constraints, OE-based prequalification limits participation only where necessary, increasing efficiency and flexibility for FSPs and consumers. Furthermore, if done properly, OE-based prequalification can ensure grid safety. However, realizing these benefits demands high-frequency measurement data, accurate forecasts, interoperable ICT infrastructure, and strong coordination across TSOs, DSOs, and regulatory bodies. Without these, the model's complexity and data requirements may undermine practical deployment.

The suitability of a grid prequalification method depends on market maturity, grid stress levels, and regulatory readiness, necessitating context-specific design choices

Evidence from KER 9 shows that no single prequalification method universally applies across all European flexibility markets. In less mature or emerging markets, such as Belgium, where distributed flexibility participation remains limited and grid violations are infrequent, adopting simpler models like prequalification via NFS can help lower market entry barriers and accelerate uptake. These approaches minimize coordination and data requirements but may compromise long-term scalability, efficiency, and grid safety as market volumes grow [10]. Conversely, in more advanced flexibility markets with high DER penetration and observable grid congestion, methods such as those with OE or full distribution network representation are more appropriate. These methods integrate DSO grid constraints or their proxy dynamically into TSO market processes, improving grid safety and utilization of distributed flexibility. However, their successful implementation requires high-resolution metering, robust data-sharing protocols, regulatory mandates for TSO-DSO coordination, and the digital and institutional capacity to process complex grid and market data in near real time. Therefore, regulatory

[5] The volume of violations is case dependent and shown as an illustration.

frameworks must evolve in tandem with technical capability to ensure model feasibility and effectiveness under specific national or regional conditions.

How can market design reduce the risk of strategic behaviour?

Basing price caps on the actual costs of non-market alternatives prevents excessive rents, discourages strategic manipulation, and ensures fair, efficient flexibility market operation.

The costs of alternative non-market-based solutions must be evaluated to determine acceptable price caps in the market, thereby avoiding the impact of strategic behaviour.
In newly developed or evolving flexibility markets, the risk of price manipulation due to limited competition and strategic bidding is significant. One key lesson from these environments is the importance of grounding price caps in the actual costs of non-market-based alternatives, such as implicit mechanisms and manual grid interventions. Without a solid cost benchmark, price caps may be set arbitrarily, i.e., either too low, discouraging participation from FSPs, or too high, enabling actors with market power to extract excessive rents. By contrast, as shown by KER 14, when price caps are explicitly derived from the cost of alternatives, they provide a transparent and economically defensible boundary for market operations. This approach acts as a safeguard against strategic behaviour, particularly in early-stage markets where liquidity is low and individual FSPs can exert disproportionate influence on clearing prices. It also ensures that the market does not pay more for flexibility than what it would cost to deploy existing non-market solutions, preserving both economic efficiency and public trust.

How can non-firm connection agreements (NFCAs) be designed and implemented to balance grid safety, market commitments, effectiveness, and fairness?

NFCAs can protect grid safety and enhance flexibility when widely adopted, but require coordination with market commitments and fairness measures to avoid undermining services or disadvantaging certain consumers.

NFCAs ensure grid safety but risk undermining market commitments
NFCAs can effectively safeguard local grid operation by temporarily limiting the import or export capacity of end-users during congestion. However, as proven by KER 10, if activated without coordination, they risk directly conflicting with FSPs' obligations in market-based mechanisms—particularly at the TSO level. For example, if a residential battery or EV charger has been prequalified and awarded a contract to provide aFRR to Elia, but the DSO activates an NFCA due to local congestion (e.g., increased EV charging before a holiday), that asset may be unable to respond when the TSO calls on the service. This conflict undermines the reliability of the TSO's ancillary service procurement and creates uncertainty for both the TSO and the FSP. D3.3 makes clear that such activation conflicts are not theoretical—they are systemically likely in future scenarios where DERs are stacked across services.

NFCAs are more effective when more consumers participate
KER 10, in its numerical study on NFCAs presented in D3.3 [23] shows that the guaranteed power limits for consumers grow as the number of participating consumers increases (see Figure 2-4). On the other hand, a larger power envelope allows for a larger availability of flexibility provision, e.g., flexibility market participation. Therefore, when a certain distribution system implements an NFCA, the flexibility

resources that can be exploited by other mechanisms, including market ones, increase, showing better effectiveness of NFCAs.

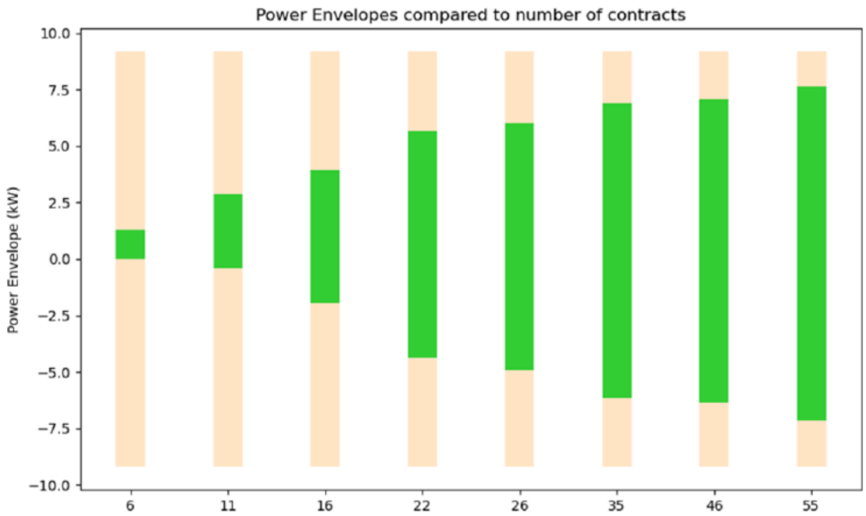

Figure 2-4 Power envelopes in NFCAs vs the number of consumers

Ensuring fairness in the NFCAs is important

As shown by KER 10 [23], consumers located closer to the transformer typically can access their full connection capacities, while those at the far end of the feeder are often more restricted, suggesting a discriminatory treatment due to locations. This issue can cause reluctance from consumers to adopt this approach. To avoid this issue, some fairness constraints must be introduced when performing the calculation of power envelopes. However, it is worth noting that ensuring fairness could result in the reduction of total OE capacity (e.g., 8% difference on the simulated case in [23]).

2.4 Value of flexibility

Flexibility helps to avoid energy system costs, as such allowing lesser investment in other flexibility technologies (batteries), a smaller electricity grid capacity, and the integration of higher levels of cheap renewable energy such as PV. However, for system operators that procure flexibility, it is important to understand how much these costs are reduced as this will give an upper limit to how much they are willing to pay for this flexibility. On the other hand, they also want to avoid remunerating consumers too little, as ALEXANDER research on preferences (see section 2.1.1) has shown that user investment in flexible EV charging capacity is dependent on a relatively high rate of return (the so-called *flexibility discount rate gap* (KER 2)). It is thus crucial to understand the level of avoided system costs and whether these avoided costs are sufficient to remunerate flexibility providers.

KER 2, 14 and 16, give further insights on this topic by answering the following questions:

- How much is saved for the system (operators)?
- Under which conditions does flexibility have value?
- Is it enough for the consumer?
- How can strategic behaviours of FSPs impact the value of flexibility and system costs?

How much is saved for the system (operators)?

EV charging flexibility helps to avoid energy system costs, providing a significant budget for remunerating flexible EV charging

Flexible EV charging reduces system costs, import dependency, and grid stress while enabling more renewables and electrification

KER 16 shows that the integration of flexible EV charging infrastructure enables a more efficient energy system planning compared to no-flexibility scenarios. Main impacts of higher EV charging flexibility include:

- Lower investment in other flexibility technologies, particularly stationary batteries: In scenarios without flexible charging, battery storage capacity can increase up to 8 times, especially in the absence of large-scale nuclear capacity.
- Lesser import dependency: Without flexible charging, net electricity imports can rise by 2–5 TWh, as the domestic system struggles to meet peak demand with variable renewables and limited flexibility.
- More renewable electricity integration and less distribution grid: High flexibility facilitates greater solar PV deployment, lowers the need for dispatchable generation (by 1.5–3 GW), and reduces distribution grid reinforcement needs.
- More electrification: Allowing flexible charging raises total electricity demand modestly—up to +3%—as the system can economically accommodate more electrified end-uses due to better peak management.

Fully flexible EV charging unlocks long-term energy system cost savings, with growing benefits from battery optimization and energy trading by 2050

In terms of system cost implications, KER 16 shows that the deployment of fully flexible EV charging yields significant economic benefits over time (see Figure 2-5). By 2040, higher upfront investments for EV charging infrastructure and expanded solar PV capacity are more than offset by carbon offsetting and savings in stationary battery savings (250-500 M€/year). By 2050, the structure of savings evolves, with battery savings becoming dominant, reaching €700–800 million annually, followed by energy trading savings (power and commodity exchanges) with an additional €500–800 million/year.

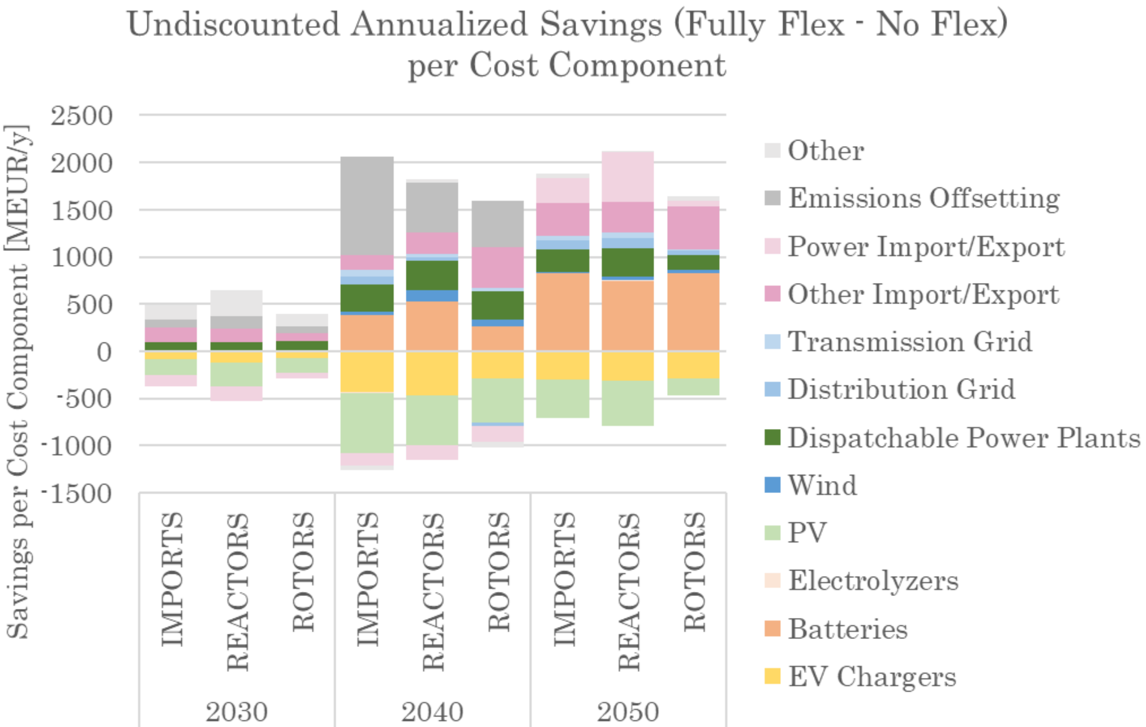

Figure 2-5: Cost Savings between Fully Flex and Non-flex scenario variants

Under which conditions does flexibility have value?

The value of flexibility could differ between different regions and depending on demographic, market and grid conditions. More research is needed, examining the differences and their impact on the value of flexibility.

Further investigation is needed on the conditions under which the benefits of explicit flexibility procurement take place

Currently, there is sometimes disagreement on which flexibility tools, processes and mechanisms should be implemented when, where and how. In Flanders, Fluvius is for instance setting up a local flexibility market. On the other hand, in Brussels, Sibelga highlighted that in the Brussels urban context, it is likely that, in the future, most congestion will be caused by EV charging. There is a risk on having market distortions as the user of the distribution grid could cause congestions while being remunerated to resolve them.

As a result, clear research and analysis is needed to understand under which circumstances, different markets and different flexibility tools function best. This is also the reason why Fluvius is setting up a market now: they indicate that it takes time to do so and consider this piloting phase of indispensable value for gaining experience and knowledge on market adaptations needed in practice. As emphasized through multiple KERs, pilots and real-life testing of the different flexibility tools and mechanisms is indeed indispensable to explore the operational, technical, and behavioural aspects of flexibility implementation before scaling up. It will also help to understand under which scenarios, for which services and grids, for which stakeholders or time periods, or under which other conditions, specific markets or tools are appropriate. Furthermore, ALEXANDER highlights that there are occasions in which specific stakeholders are not willing to share data. ALEXANDER studies different types of flexibility mechanisms, highlighting their benefits and disadvantages. As there is no one-size-fits-all solution, it is therefore important to take a closer look at the different conditions that determine which solution fits best in which situation.

To support these analysis, additional tools are needed such as scenario analyses which consider both the evolution of technologies (e.g. EV uptake, heat pumps) and their impact on the distribution grid (e.g. local congestion forecasting) are therefore crucial. These scenarios help define under what system conditions and technological developments explicit flexibility procurement brings the most value. Understanding such effects requires not only technical modelling but also insights into stakeholder behaviour and decision-making. This can be achieved through DCEs and simulation models that capture market interactions among actors under different market design scenarios—as explored in D4.1 of the ALEXANDER project.

The value of flexibility depends on the possibility of value stacking.
KER 12 shows that market coordination schemes can play a crucial role in allowing for value stacking. For instance, if distribution-level FSPs are permitted to participate in local and TSO-level markets, their chances of being cleared and activated increase. Furthermore, if markets are not well coordinated, then they may unnecessarily block flexibility (for instance, depending on the prequalification method as discussed in section 2.3.2). As explained in [10], alignment of DSO-TSO markets, products, roles, and the different market phases (prequalification, procurement, settlement) will facilitate value stacking (which should have a positive impact on market liquidity and FSP engagement), and it will decrease system costs[6] as market liquidity increases.

Incentives need to be shaped properly (right granularity, right timing, accounting for preferences…)
As indicated in the section on incentives, KER 4 shows that using the right granularity in price incentives, leads to a significant drop in system costs. When real-time pricing is paired with a capacity-based distribution tariff, total Belgian energy system costs drop by approximately €220 million per year compared to a flat pricing and volumetric tariff baseline. Even with less granular 6-hourly pricing, 90-95% of these savings can still be captured, showing that moderate granularity is nearly as effective as real-time signals while being easier for households to manage. (see Figure 2-6 and [32]).

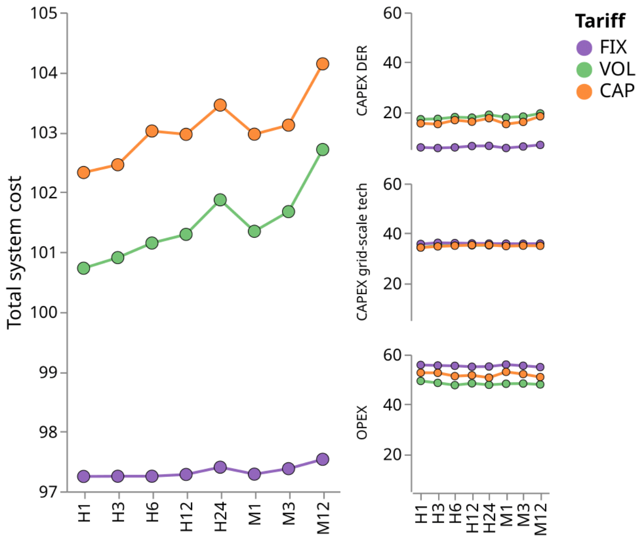

Figure 2-6: Total system cost and constituents: CAPEX in DER, CAPEX in grid-scale technologies and OPEX. Costs are normalized using the lowest occurring total system cost: H1

[6] For instance, in the simulated case in [31], the system cost decreases by up to 24% when the sequential market scheme, which allows value stacking, is put in place as compared to the separate (disjoint) markets, which do not allow value stacking.

FIX tariff total system cost. FIX: fixed tariff, VOL: volumetric tariff, CAP: capacity tariff, H: hourly temporal granularity, M: monthly temporal granularity.

A moderate increase in the total procurement cost is expected when grid safety measures, e.g., grid prequalification, bid aggregation, or an ex-post corrective market, are put in place, but these measures are essential to fully harness all available resources
KER 12 through [23] shows that adding any grid safety measures proposed in the ALEXANDER project increases the total procurement cost as compared to the idealized but impractical market schemes, where the representations and constraints of all electrical networks involved are taken into account. However, the increase is moderate, e.g., it ranges between 1-10% for the cases presented in [23], and does not outweigh the benefits of having this measure, i.e., ensuring grid-safe activation of distributed flexibility.

Is it enough for the consumer?

Flexibility will only scale if consumer incentives are timely, transparent, and aligned with both investment costs and perceived value.

By 2050, system savings are more than sufficient to cover user remuneration for flexible EV charging—but bridging the gap by 2030 remains a key challenge
Choice experiments show that *flexibility providers* on average require a minimum annual remuneration of around 28% of their additional investment costs, corresponding to some 46€ per year for flexibility only and 177€ per year for flexibility with V2Home and Grid[7]. KER 16 shows this level of remuneration is generally possible for all tested scenarios, especially over the longer term (from 2035 onwards). In the REACTORS scenario, for example, the 2050 annual remuneration budget *per EV driver*[8] for V2Home and Grid equals 817€, which should be amply sufficient to cover the estimated 177€ minimum annual reward. Yet, in 2030 remuneration budgets are more critical, with per driver budgets for flexibility only of the order of 20€ annually. Whether remuneration budgets are enough critically depends both on the number of EVs per charger, as well as on the cost difference between flexible and non-flexible charging technologies. If the flex EV charging investment could be 'rationalized', the expected annual reward could drop, which would make the case for flexible EV charging easier. Furthermore, possible additional benefits for grid operation, not considered in our modelling approach, may further improve flexible charging business cases. How to translate avoided system costs to user remuneration in practice, via tariffs and incentives, is an important next step which falls out of the scope of this study.

[7] reflecting a discount rate of on average 28% and assuming a 15yr lifetime and additional investment cost of 206€ for flexibility only and 789€ flexibility with V2Home and Grid
[8] remuneration budgets are calculated as the net avoided energy system costs divided by the number of representative chargers or number of EV drivers

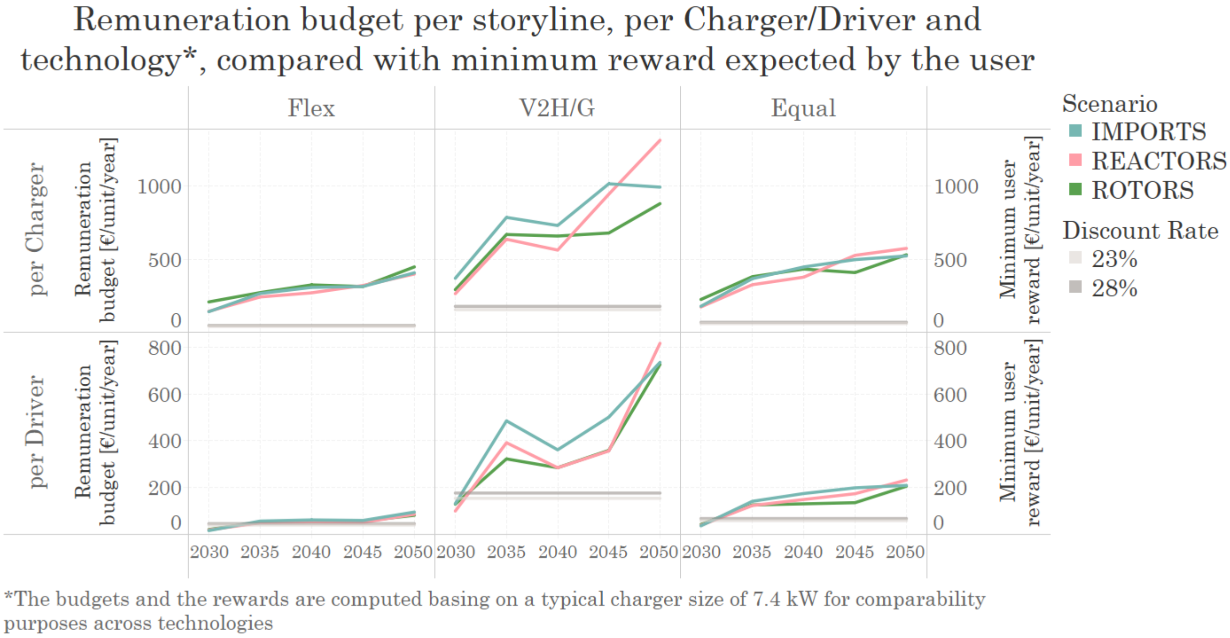

Figure 2-7: Remuneration budget in the different scenarios, for the different calculation methodologies.

Integration of consumer preference in energy system planning models requires a paradigm shift
LV flexibility can lower adequacy requirements for the energy system. However, LV flexibility is in the hands of consumers who may not operate their assets optimally (for the system) as the consumer may value the use of flexibility not only based on budget but also on control and comfort (as shown in KER 2). Energy system planning models need to account for this consumer preference. For existing models, KER 16 showed that the more practical approach is to consider consumer preference indirectly during a post analysis of the results. Yet, from discrete choice experiments we can identify levers and responses that can be considered directly at the level of the decision process. KER 16 therefore also showed an alternative approach where the energy system planning model considers the consumer preference for the adoption of flexible chargers when the annual reward or the minimum battery level changes. While that modelling exercise shows us that the integration comes with certain challenges, we also see that the model is able to produce more realistic results for the value and use of flexible EV chargers (albeit for a more limited setup). Realistic results mean, of course, that the flexibility potential is lower and the cost is higher. Although, overall, flexible EV chargers remain valuable to the system. More details on that modelling exercise can be found in D4.2. Ideally, energy system planning models continue development with consumer preference. But, practically, in the near-term consumer preference needs to be dealt with during the analysis with an energy system planning model.

How can strategic behaviours of FSPs impact the value of flexibility and system costs?

Strategic behaviour, especially in nascent markets, can reduce market efficiency and lead to price manipulation, thereby increasing system costs.

The reduction of market efficiency in newly developed markets due to low liquidity can be amplified by the strategic behaviours of FSPs
Newly established markets often suffer from low liquidity, characterized by a limited number of participants and low trading volumes. This scarcity of transactions can hinder price discovery and reduce overall market efficiency, as the system lacks the depth necessary to reflect true value signals

and marginal costs. Moreover, this inefficiency is further exacerbated when FSPs engage in strategic behaviour. In nascent markets, the ability of individual actors to influence prices or manipulate bidding strategies increases due to the limited competition and reduced oversight mechanisms. KER 14 shows that such behaviour can lead to suboptimal dispatch outcomes and inflated costs, particularly in the absence of strong regulatory safeguards and transparency. Consequently, the combination of low liquidity and strategic behaviour not only undermines the operational reliability of the market but also delays its maturation toward higher efficiency and trustworthiness.

Higher system costs are expected when some FSPs can perform price manipulation by aggregating flexibility resources

The aggregation of flexibility resources by certain FSPs can unintentionally concentrate market power, particularly in markets with low liquidity or limited competition. While aggregation is essential to unlock small-scale flexibility and enable their participation in energy and balancing markets, it also increases the influence an FSP can exert over market outcomes. KER 14 shows that when a single FSP aggregates a substantial volume of flexibility assets, especially in localized or newly formed markets, it may be able to influence clearing prices through strategic bidding, thereby distorting the price signal and reducing overall market efficiency. Such manipulative behaviour may not be easily detected, particularly in markets lacking robust monitoring mechanisms or where transparency is limited.

2.5 Governance

As flexibility acquisition moves closer to the LV level, the need for clear and coherent governance becomes increasingly apparent. Governance provides the overarching framework that enables technical, market, and social innovations to function effectively within a reliable and equitable energy system. It encompasses several interlinked dimensions. First, the **institutional and regulatory framework** defines roles and responsibilities, market design principles, and the rules for data governance and interoperability. Second, **governance processes and coordination mechanisms** ensure alignment across actors and system levels—for instance through effective TSO–DSO coordination and stakeholder engagement. Third, **market governance** addresses the fair distribution of costs, benefits, and risks among stakeholders, promoting trust and long-term participation. Finally, **infrastructure governance** safeguards both the physical and economic resilience of the system, ensuring that digitalisation, cybersecurity, and dependency risks are properly managed. Achieving effective flexibility at the LV level therefore requires moving towards an integrated governance structure—one that bridges these dimensions and allows for adaptive, transparent, and coordinated decision-making across the energy system.

2.5.1 Institutional and regulatory framework: Roles

The energy transition creates new responsibilities which leads to new roles being developed, or roles being expanded with new responsibilities due to the fact that new activities are being developed. While the energy transition has an influence on the responsibilities and possible new activities of many stakeholders, ALEXANDER pinpoints a key influence on three roles, as such, answering the following questions through combined analyses of all KERs:

- How should existing roles adapt or new roles be shaped to facilitate LV flexibility delivery?

How should existing roles adapt or new roles be shaped to facilitate LV flexibility delivery?

The energy transition expands and redefines the roles of community managers, DSOs, and market operators, demanding formal mandates, governance, and technical capabilities to coordinate flexibility effectively and maintain trust.

The community manager: A critical bridge between energy communities and the power system
KER 7 and KER 15 include in their flexibility solutions a required new role. The growth of energy communities—groups of prosumers, consumers, and distributed energy resources pooling resources for mutual benefit—has introduced a new layer of complexity into electricity markets and system operation. While these communities have the potential to contribute to system flexibility, local balancing, and renewable integration, they also create challenges in aligning individual member priorities with wider system requirements. Community members may value different things, such as cost savings, comfort, or maximising renewable self-consumption, whereas DSOs, TSOs, and market operators require flexibility, peak shaving, or voltage control. Without a dedicated community manager (CM), there is no structured process to reconcile these diverging objectives into coherent operational strategies that satisfy both members and the energy system. The CM is responsible for orchestrating internal energy sharing and flexibility provision, ensuring that the community's generation, storage, and controllable loads are scheduled efficiently, internal prices are set fairly, and benefits are allocated transparently. At the same time, the CM acts as the community's interface with external actors, validating flexibility commitments, ensuring compliance with technical constraints, and managing data exchange and settlement processes. This is particularly important for managing uncertainty and behavioural variability, as CMs require real-time monitoring, behaviour-aware forecasting, and adaptive pricing or scheduling tools to respond to deviations in user behaviour or PV

output. However, the role is currently undefined in most regulatory frameworks, leaving CMs without guaranteed data access, clear accountability, or neutrality safeguards. Formalising the CM role would provide legal clarity, operational capability, and standardisation, making it possible for communities to scale effectively and integrate as reliable partners in coordinated TSO–DSO flexibility markets.

The pace and depth of DSO evolution from passive actors to active SOs depend directly on enabling conditions being in place.
All KERs, one way or another, highlight the fact that DSOs (should) progressively transition from passive grid custodians to active system co-operators, assuming increasingly complex responsibilities depending on the chosen coordination model and local system readiness. DSO responsibilities in flexibility procurement evolve through three distinct stages. In the early phase, typical of separate procurement models, DSOs act primarily as passive grid protectors, validating or blocking external activations to avoid local grid violations—often due to low observability and regulatory uncertainty. As they develop capabilities like monitoring, local need identification, and bid evaluation, DSOs transition into active flexibility managers, directly procuring services (e.g. via local flexibility markets) and coordinating with TSOs. In the most advanced stage, under coordinated or common market models, DSOs become fully integrated system operators, co-defining products, participating in joint markets, and sharing operational and settlement responsibilities with TSOs. This final role marks DSOs as key actors in delivering system-wide, multi-level flexibility.

However, it is essential to ensure that DSOs also have all the means to execute and proceed towards these new responsibilities. ALEXANDER shows that the shift from passive grid observer to active system co-operator requires DSOs to build a foundation of **technical, institutional, and regulatory enablers** which multiple actors could assist in making sure they are in place.

1. First, grid observability is critical—it allows DSOs to assess local impacts and manage congestion proactively.
2. This must be backed by digital infrastructure, including integrated IT/OT systems, automated controls, and APIs for real-time coordination.
3. Standardised data exchange protocols are necessary for seamless collaboration with TSOs and FSPs, especially in joint procurement and validation processes.
4. DSOs with pilot experience, such as Fluvius, are better positioned to scale their role. In this regard it is important to allow for testing in a more ‘agile’ way. Regulatory sandboxes could be a facilitating policy instrument, however this regulation differs between the three Belgian regions. In February, the Flemish Parliament submitted a new concept note on regulatory sandboxes and innovation in Flanders [33]. Yet, it is important that all Belgian DSOs have the same opportunities, especially in the context of proper SO-coordination.
5. Additionally, clear regulatory mandates, covering flexibility procurement obligations and cost recovery, are essential to legitimize DSO actions. In this regard, remuneration mechanisms need to be properly supported (e.g. CAPEX versus TOTEX approach, ensuring that both operation expenditures (e.g. purchasing flexibility) and capital expenditures (e.g. grid reinforcements) are properly balanced) and there should be specific incentives linked to innovation. In its latest investment plan, Fluvius expresses concerns in terms of the financial feasibility of the requirement investments in the long-run [34].
6. Foundational “no-regret” actions, like prequalification processes, local need identification, and activation validation tools, are vital in preparing for any coordination model.
7. In terms of feasibility, it needs to be acknowledged that DSOs also need to have time and resources to be able to adapt. For instance, Fluvius indicated in its investment plan 2026-2035 that it scaled up its organisation from 2023 to 2026 by searching additional financial means to buy materials, hire additional people and contract additional third parties.

8. From a regulatory perspective, it is equally important that European regulation is transposed to national and regional regulation in a clear, transparent, and timely manner, while openly discussing and coordinating with the relevant stakeholders.
9. Lastly, the involvement of third-party market operators can significantly reduce complexity; in their absence, DSOs must internalize this role.

Market operators as neutral coordination hubs in integrated flexibility markets
As flexibility procurement increasingly spans both DSOs and TSOs, KER 12 emphasizes that the role of the market operator must evolve beyond their traditional role of running individual markets into neutral coordination hubs that manage the complex interplay between grid levels. In integrated flexibility markets, the role of the market operator is not only responsible for matching bids and offers, but also for aggregating, filtering, and prioritising bids in a way that respects both local distribution constraints and system-wide requirements. In this regard, one might also wonder whether this requires an extension of the current role of the market operator, or whether it implies the development of a new role that would take up these responsibilities. Alternatively, it is also possible that these responsibilities are divided among a multitude of roles, implying the expansion of multiple roles. This is because these responsibilities also require the capability of handling asymmetric readiness among DSOs—some operating fully developed local flexibility markets, others still in pilot phases—while ensuring full interoperability with existing TSO markets. Without this modularity, integration ambitions risk stalling in fragmented implementations that diminish liquidity and efficiency.

A critical enabler of this expanded or new role is a clear governance framework that fixes the legal status of the role of the market operator, guarantees neutrality in bid and activation management, and establishes transparent rules for data rights, settlement processes, and conflict resolution. This is especially important where DSO and TSO interests overlap, as disputes over activation priorities or data access can undermine trust in the market's fairness and reliability. The governance model must ensure that market operators have the authority to coordinate across all relevant parties, while remaining independent from commercial or operational biases. Given the sensitivity of grid and market data, operators must also implement robust cybersecurity measures and adhere to privacy-by-design principles.

If designed and governed effectively, the role of the market operator can serve as the backbone of TSO–DSO integration, enabling seamless coordination, efficient use of flexibility resources, and enhanced market transparency. Without this neutrality and coordination capacity, integrated markets risk becoming fragmented, less liquid, and less trusted by both system operators and market participants, ultimately reducing their value for system optimisation.

2.5.2 Coordination and integration

Flexibility requires multiple domains to come together: technology, data, regulation, research, behavioural aspects, roles… Often these are studied independently from one another. However, multiple ALEXANDER KERs (KER 1, KER 2, KER 12, KER 16 and KER 18) highlight the importance of all these domains to work together. True system flexibility cannot be achieved by addressing only one layer in isolation, as each domain both enables and constrains the others. For example, technological solutions depend on robust data streams, but their impact is mediated by regulatory frameworks and the willingness of end-users to adapt their behaviour. Similarly, innovative market designs remain theoretical if not supported by technological feasibility and social acceptance. The ALEXANDER KERs underline that progress in flexibility is only possible when insights are integrated across disciplines and actors, aligning technical innovation with governance, market roles and behavioural incentives. This requires interdisciplinary collaboration, iterative learning processes, and governance mechanisms that actively bridge gaps between research, practice and policy.

Governance processes and coordination mechanisms

Achieving system flexibility requires breaking down silos between technology, markets, regulation, and behaviour. Coordinated action — built on trust, shared data, and common valuation frameworks — enables all actors to align their objectives and turn flexibility from theory into practice.

Integration between different fields of expertise — both theoretical and practical, and between technical and socio-economic domains — must start before flexibility needs become urgent, markets mature, or large-scale deployments are in place

In Belgium, flexibility acquisition is still an immature field. The gap between theory and practice remains wide: many concepts proven in modelling or academic research are still perceived as far-fetched or impractical by practitioners. Moreover, there is a clear information gap between **social and market expertise** on the one hand, and **technical expertise** on the other. Work is still largely done in silos, which has several consequences:

- **Technical optimisation often ignores behavioural realism.** As shown in KER 1, KER 2, KER 16 and KER 18, assuming perfectly rational, price-responsive consumers can lead to significant over- or under-estimation of flexibility potential. Without integrating realistic behavioural responses, coordination frameworks risk misjudging the actual capacity available when needed.
- **Lack of 'interconnecting' roles bridging disciplines.** KER 15 stresses the importance of clearly defined coordination actors, such as a *community manager* role, to align the actions of prosumers, system operators, and markets. KER 12 underlines the need of neutral market facilitator as an interface between local actors and system operators, but also between system operators. Without these bridging roles, each domain optimises in isolation, missing opportunities for synergy.
- **Trust takes time to build and is easily damaged.** Misinformation, unclear responsibilities, and uncertainty in benefits or risks undermine cooperation between consumers, aggregators, DSOs, and TSOs. However, as highlighted in KER 12, even between market entities, institutional trust between DSOs, TSOs, aggregators, especially around data sharing is indispensable.
- **Concerns about loss of control are shared by all actors.** Consumers fear losing autonomy over their assets; grid operators fear losing control over network stability if flexibility is activated without full visibility or safeguards.

Integration maturity depends on piloting, feedback loops, and cross-actor learning

Many KERs indicate that current models are still at TRL 2–4. Scaling towards deployment will require field trials, iterative adjustment, and capacity-building for community managers, aggregators, and DSOs. These actors must be trained not only in the use of optimisation tools but also in translating model outcomes into operational, regulatory, and market-relevant actions.

Value-oriented alignment is a coordination enabler

Experience from both the socio-economic and technical domains shows that coordination succeeds when all actors can see and quantify the value of flexibility for their objectives — whether this is reduced bills and greater autonomy for consumers, improved market participation for aggregators, or deferred investments and operational stability for DSOs. This requires shared valuation frameworks that connect technical impacts with economic and social outcomes, making trade-offs transparent and acceptable to all parties. Valuation should include avoided investments, operational reliability, and user benefits. Value perception is not equally shared across actors. A recurring finding across KERs is that while consumers value bill savings and autonomy, DSOs and TSOs require clear quantification of avoided investments, congestion relief, and system stability gains. If the valuation frameworks used in coordination focus too heavily on one perspective, participation and investment from other actors may falter. D3.3 confirms that shared valuation methods — covering technical, economic, and social benefits — are necessary to sustain long-term collaboration.

Operational coordination depends on robust, shared data frameworks
Effective policy, market design, and implementation require a solid understanding of impacts across the system, infrastructure, and individual stakeholders. Access to the right information is essential to make balanced decisions that enhance efficiency, reliability, and fairness. However, turning data into actionable information remains a challenge. Two main barriers stand out.

Challenge 1: Limited data availability. In many areas, the necessary data are simply not available or accessible. This is particularly the case for grid data, where the absence of smart meters or metering equipment limits observability. A regulatory push is needed to accelerate the deployment of smart meters and to clarify how these data can be used responsibly. At the same time, analytical tools, such as those developed in D3.1 (KER8: Congestion forecaster), can help overcome current data gaps. By applying smart statistical techniques, these tools enhance grid observability even where direct measurements are lacking.

Challenge 2: Translating data into the right information signals. When data are available, the next step is to extract the right information to guide decisions and actions. The key question is not how much data we have, but how well we can translate them into meaningful signals for market participants and system operators. This requires a clearer understanding of how different actors respond to information and incentives — an area addressed in ALEXANDER. Importantly, it should be noted that not all data should be openly shared to achieve this. Grid data sensitivity and privacy concerns limit what can be disclosed. Therefore, the focus should be on aggregating and transforming data into actionable signals and transparent information that support efficient market behaviour while protecting confidentiality.

Market governance

Belgium's flexibility markets are still emerging, with regional DSOs progressing at different speeds and TSO–DSO coordination in its early stages. The ALEXANDER project identifies a stepwise pathway with "no-regret" measures to enable gradual, yet coordinated, evolution toward more advanced market schemes.

Belgian's explicit flexibility procurement by DSOs is still in its infancy, with regional DSOs moving at different speeds. TSO-DSO coordination is therefore also still immature
KER 12, more particularly D3.2 and 3.3 [10], [35] highlights that only in Flanders, Fluvius is currently experimenting with a real-life local flexibility market to procure services for voltage control and congestion management. Furthermore, in the Walloon area, ORES is in the preparatory phase to set up a local flexibility market. RESA and Sibelga are currently not yet considering setting up a local flexibility market. This divergence in maturity across the Belgian DSOs means that Belgium currently cannot adopt a one-size-fits-all policy for DSO procurement. National coordination efforts must therefore accept and embrace asymmetry, enabling regional flexibility while ensuring strategic alignment.

Proper TSO-DSO coordination has proven to lead to a higher value of flexibility due to higher grid safety and higher market efficiency. However, these benefits need to be balanced against the costs of setting up such coordination

The common market scheme, i.e., a single market where all SOs jointly procure their flexibility, has been shown to have the best market efficiency (lowest total procurement cost) [31]. Furthermore, as such markets take into account grid constraints of all relevant electrical networks, grid safety of the entire system is guaranteed. However, this market scheme is the most challenging to set up, and is not realistic under the current regulations [35]. On the other hand, fully disjoint uncoordinated markets are the least efficient as each market can only exploit flexibility resources available in its network. The sequential market scheme, where flexibility resources are allowed to be forwarded (either manually or automatically) from one market to another, is seen to be the scheme that provides good compromise and can realistically be implemented in the near future [35]. In such market scheme, the level of coordination, e.g., in terms of data sharing, can still be limited, while market liquidity is higher as compared to the separate scheme, potentially resulting in lower procurement costs.

ALEXANDER formulated no-regret measures to move more easily from less mature to more advanced market (coordination) schemes, allowing asynchronous progress

The ALEXANDER project compares different market models for explicit flexibility procurement and outlines a pathway for progressively increasing coordination between TSOs and DSOs, leading to more advanced market designs. As highlighted in KER 12 and discussed in section 3.5.1 on coordination, greater TSO-DSO coordination leads to lower flexibility procurement costs. However, in Belgium, DSOs are still in the preparatory or piloting phase of setting up local flexibility markets—or in some cases, not yet considering explicit flexibility procurement. As a result, the first market schemes being developed require less coordination with the TSO.

To ensure future readiness, the ALEXANDER project highlights four flexibility coordination clusters. For each cluster, no-regret market design measures are identified—actions that should be taken regardless of the chosen model to keep open the option of progressing toward more advanced schemes if desired. This allows DSOs to progress at different speeds, without undermining overall system evolution.

Clusters 1 through 3 can be seen as sequential steps toward deeper coordination, while Cluster 4 complements them by focusing on the integration of non-market-based flexibility mechanisms. Below, each cluster is described along with its definition, the conditions under which it is applicable, and the no-regret measures recommended for its implementation.

- **Cluster 1 – TSO-only procurement**: In this initial setup, the flexibility market is exclusively operated by the TSO—reflecting the current business-as-usual situation in Belgium. The DSO has very limited visibility into its own grid, making grid transparency a top priority. This is crucial for proper prequalification of assets (for all use cases) and for accurately identifying flexibility needs, which is also necessary under more advanced coordination schemes. Key no-regret actions in this cluster include:
    - Developing prequalification tools to prepare for future procurement of distribution-level resources.
    - Establishing data governance frameworks to facilitate information sharing between system operators—e.g., via a flexibility register.
    - Building a robust data infrastructure, especially to leverage data from the rollout of smart meters.
- **Cluster 2 – TSO-DSO separate procurement**: In this model, DSOs set up their own flexibility markets (e.g., for congestion management), while the TSO continues operating its own market. This assumes that the foundational elements from cluster 1 (visibility, data governance,

prequalification) are already in place. The emergence of multiple markets—DSO, TSO, and wholesale—creates the need for alignment. Key no-regret actions and conditions include:

  - Harmonizing processes such as prequalification and market timing to avoid inefficiencies.
  - Ensuring product compatibility across markets without making participation too complex for FSPs.
  - Promoting market liquidity and consumer engagement to support participation from all actors and enable a smooth transition toward more advanced coordination.

- **Cluster 3 – TSO-DSO joint procurement**: This cluster introduces full co-optimization, where TSOs and DSOs jointly procure flexibility—potentially through a common market. It is the most demanding setup, requiring full alignment of market processes and products. However, this model should not necessarily be seen as the automatic end goal. Key no-regret actions and conditions for this cluster include:
  - Conducting grid- and scenario-specific cost-benefit analyses, since the optimal setup may vary per DSO or grid area.
  - Considering simplified alternatives to the common market—such as the model demonstrated by ALEXANDER—which deliver nearly equivalent benefits with less complexity, especially in terms of data management.
  - Recognizing that some system operators may view a fully integrated market as too futuristic or unrealistic, reinforcing the need to explore pragmatic co-optimization alternatives.
- **Cluster 4 – Combination with implicit flexibility mechanisms**: This cluster is designed to coexist with clusters 1 to 3 and focuses on combining market-based mechanisms with implicit flexibility tools such as connection agreements and network tariffs. The main challenge is ensuring that these mechanisms support one another rather than work at cross-purposes. Key no-regret actions and conditions include:
  - Assessing the complementarity and potential of different flexibility mechanisms, both individually and jointly.
  - Comparing the benefits of these mechanisms with their implementation costs.
  - Ensuring transparency around how these tools interact, and conducting tailored studies per grid area to determine the best-fit approach—since one-size-fits-all solutions are unlikely to apply here.

Harmonization does not mean uniformity—context matters

KER 12 and D3.3 [35] emphasize that harmonization across Belgian regions should focus not on enforcing identical internal processes, but on ensuring compatibility at critical interfaces—such as data exchange formats, product definitions, and prequalification outputs. Given the substantial variation in grid topology (urban Brussels vs. rural Wallonia), digital meter rollout, and the choice of flexibility market platforms (e.g., Fluvius using NODES, others undecided), we should strive for harmonisation only where it is possible. Where harmonisation is not entirely possible, we should aim for local and regional adaptations where needed. This entire process will most likely be a gradual process due to the previously mentioned differences between the regions. Furthermore, ALEXANDER recommends aligning the outputs that matter for system-wide coordination—such as ensuring that flexibility bids are grid-safe, prequalified using transparent criteria, and structured in ways that support bid forwarding and value stacking across TSO and DSO markets. This allows DSOs to maintain autonomy in how they develop their local processes while still contributing to a functional, interoperable flexibility ecosystem.

Coordinated market schemes pool flexibility from different systems, enabling the reduction of market power risks

A key insight from KER 14 is that coordinated market schemes, in which flexibility is pooled across multiple system operators, can play a pivotal role in mitigating market power risks. In isolated or localized markets, a limited number of FSPs may control a substantial share of the available resources, increasing the risk of strategic bidding or price manipulation. However, when flexibility resources are coordinated across different systems, such as through TSO-DSO coordinated markets, the size and diversity of the resource pool increase, enhancing competition and diluting individual market influence. As shown in D4.1 indeed, the fragmented market scheme, where markets are isolated and not connected, is more negatively impacted than the coordinated ones (common and sequential market schemes).

2.5.3 Infrastructure governance: Data

The energy transition is generating an unprecedented demand for reliable, timely, and multi-domain data. However, one key element that ALEXANDER is emphasizing, is that it is not only about that data. Instead, what matters is the information that is retrieved, obtained and shared from these data. Decisions on market design, regulation, grid management, consumer engagement, and technology adoption increasingly rely on information that is accurate, granular, and accessible. This distinction between data and information is important, data is sensitive, dynamic, and often fragmented across actors and domains, making its governance a central challenge. Striking the right balance between availability, usability, privacy, and security of data is therefore often challenging. Against this backdrop, the ALEXANDER KERs provide valuable insights into how information can be collected, shared, and applied to support evidence-based policymaking, safeguard system reliability, and strengthen market efficiency.

- How can data/information best support the energy transition while addressing the challenges of access, privacy, and system reliability?

How can data/information best support the energy transition while addressing the challenges of access, privacy, and system reliability?

High-quality, accessible, and well-governed information (rather than data) is essential for reliable system operation, effective policy design, and market oversight. It must therefore be examined how information can be spread most efficiently, as challenges around data availability, standardisation, privacy, and sharing can block the full potential for the energy transition.

Data is not the end-goal: information is.

As indicated in one of the previous learnings: the key challenge is turning data into actional information and sharing this information. To do so, we obviously need data, who then secondly, need to be transformed into useful information. It is important to emphasize this because quite some actors are asking for data, while what they need is information. They want to be informed to be able to do the "right" thing. It is therefore important to ensure that there are proper tools to analyse data, to ensure that the right information signals can be given to different stakeholders. The following learnings indicate insights that ALEXANDER got on how to analyse specific data.

Granular, high-quality data enables robust analysis
KER 5 demonstrates that reliable, centralised, and granular datasets are vital for assessing technology adoption patterns and policy effectiveness. Using municipality-level PV adoption data from Flanders and Wallonia, KER 5 was able to compare different incentive schemes directly—an analysis made possible only because PV registration data is complete and standardised. However, the KER notes that similar high-quality data is lacking for heat pumps, retrofits, and EVs, limiting evidence-based decision-making. The recommendation is to establish centralised access to such datasets, to support comparable analyses for other energy technologies.

KERs 9, 10 and 11 highlight the importance of integrating more dynamic grid calculations to ensure grid-safety. This as well requires up-to-date, real-time grid data.

However, KER 13 also shows that in some cases, making use of more data-driven aggregated data, avoids intrusive, appliance-level monitoring. By inferring group-level behaviour from historical aggregate consumption data, the approach preserves privacy while providing operationally useful parameters for aggregators and BRPs. The KER notes that this method could support large-scale LV flexibility without requiring extensive direct control or personal data collection, making it more acceptable to consumers and GDPR-compliant.

Continuous behavioural and market data collection is essential for policy alignment
Multiple ALEXANDER KERs (notably KER 1 and KER 2) show that continuous, high-quality data on consumer preferences and behaviours is critical for effective regulation and market design. KER 1 highlights that policymakers require ongoing information to refine regulatory frameworks for energy communities, aggregators, and prosumers. KER 2 confirms that regional and temporal variations in tariff structures influence willingness to participate in flexibility schemes, and that only panel data can reveal the causal effects of such changes over time. Both KERs recommend institutionalising periodic preference surveys and integrating results into planning, ensuring that regulation remains responsive to evolving consumer behaviour. Many KERs emphasise that consumer preference data changes over time due to shifts in income, awareness, or social influence, and should therefore be collected annually to maintain the realism of modelling results. Access to current preference data allows for better calibration of investment, adoption, and flexibility behaviour in models, ensuring they remain relevant in dynamic market contexts.

Data from market monitoring is crucial to mitigate strategic behaviour
KER 14 underscores the critical role of market data in enabling effective oversight of market dynamics. Such data is essential not only for monitoring market activity but also for detecting, analysing, and understanding potential instances of strategic behaviour by market participants (FSPs). By systematically collecting and analysing relevant data, regulators and SOs can identify patterns that may indicate market manipulation, inefficiencies, or behaviours that could undermine competition and system reliability.

Effective system management requires both resilient methodologies and high-quality data
Findings from KER 8 highlight that effective forecasting and operational decision-making depend on a balanced combination of two factors: robust methodologies capable of functioning with incomplete or imperfect datasets, and a commitment to securing accurate, complete, and representative data. While advanced algorithms can be designed to tolerate certain gaps or inaccuracies — for example, by leveraging available measurements to improve observability and anticipate issues — there remains a

critical threshold beyond which missing or flawed data will undermine results. In particular, inaccurate or incomplete interconnectivity information, such as errors in cable switching configurations or phase allocations, can render even the most sophisticated forecasting tools unreliable. Similarly, KERs 9, 10, and 11 require high-quality data to obtain an accurate proxy of a distribution system in the form of either operating envelopes or network constraints. This demonstrates that long-term success in areas such as congestion management and flexibility activation relies on parallel investments in methodological resilience and in the systematic collection, maintenance, and validation of essential datasets.

Data collection challenges hinder modelling of certain analyses

KER 5 reports significant difficulty in obtaining sub-regional DSO network tariffs and calculating benefits from incentive schemes, which required manually compiling data from numerous DSO and TSO reports. This illustrates the need for streamlined, standardised data provision from network operators. KER 9, 10, 11 and 12, even though already implemented for some other European networks (like in the Finnish OneNet Demo), currently cannot make realistic comparisons between all Belgian regions due to the fact that grid data (for good reasons) are not publicly available. Therefore, this poses limitations on more concrete, quantified evidence specifically for Belgium and makes it hard to make a realistic comparative analysis capturing the differences between the regions.

Privacy and cybersecurity, but also exposure of sensitive data concerns shape data access and use

Several KERs (KER 1, KER 6, and KER 7) identify privacy concerns as both a barrier to data collection and a determinant of user trust. KER 1 calls for cybersecurity and data protection regulations to safeguard consumer trust in flexibility programs. KER 6 highlights that reluctance to share preference data can limit the scope of behavioural modelling. KER 7 warns that increased real-time monitoring for community optimisation raises cybersecurity risks. Together, these findings underscore the need for privacy-by-design data collection methods and robust regulatory protections to balance insight generation with consumer rights.

In terms of grid data, one of the persistent obstacles in TSO-DSO coordination is the reluctance to share detailed distribution grid models and real-time operational data. These datasets often contain commercially sensitive, and security-critical data. Sharing them in full between operators — or with a third-party market operator — raises risks. KERs 9 and 11 provide grid safety measures that limit the exchange of grid data between DSOs and a market operator, avoiding these risks. For instance, the bid aggregation mechanism, lets DSOs process flexibility offers internally, check them against local grid limits, and compile them into a grid-safe aggregated curve (Residual Supply Function) for the TSO without revealing detailed grid data. This preserves confidentiality, supports operational security, and enables coordination without full data sharing—critical in Belgium's multi-region, data-sensitive context. While it reduces granularity and requires clear aggregation rules, trust mechanisms, and defined responsibilities, it offers a practical, no-regret step toward higher coordination without forcing immediate regulatory or ICT overhauls.

Multi-domain data integration strengthens policy relevance

KER 13 and KER 5 show that combining technical system data (load profiles, PV availability), economic signals (tariffs, wholesale prices), and socio-economic characteristics (demographics, discount rates) produces more robust analyses. KER 13's inverse optimisation framework relies on historical aggregate consumption data linked to real-time prices, while KER 5's statistical model combines adoption data with incentive scheme design. Such multi-domain integration improves the accuracy of scenario modelling and the targeting of incentives or tariffs.

3 Conclusions and Recommendations

This chapter builds directly on the key lessons presented in chapter 2, shifting from analysis to implementation. While the previous chapter outlined what is required to make LV flexibility work in practice, this chapter focuses on how to make it happen. Drawing on the full evidence base developed in ALEXANDER, it translates the project's insights on consumers, grids, and market design into concrete policy, regulatory, and operational actions.

The recommendations are structured around five action domains that together determine the success of flexibility implementation: **regulation, incentives, communication and knowledge sharing, tooling and infrastructure, and future research and development.** These dimensions reflect both the technical and institutional logic of flexibility—linking the rules that govern it, the signals that activate it, the understanding that sustains it, and the infrastructure that enables it.

In short, this chapter moves from the *what* to the *how*: from understanding flexibility to building the systems, institutions, and relationships that can deliver it. The recommendations are grounded in ALEXANDER's empirical findings and designed to guide policymakers, DSOs, TSOs, aggregators, and community actors in creating a fair, efficient, and scalable flexibility ecosystem.

3.1 Regulation - Policy and transition planning: Building a coherent framework to support flexibility implementation

ALEXANDER shows that the success of LV flexibility does not depend solely on technology or consumer engagement—it hinges on the coherence of the regulatory framework that ties these elements together. Current regulation remains fragmented across regions and stakeholders, for instance leading to differences between regions in flexibility mechanisms and flexibility uptake, and data access. With the new activities and changes in responsibilities of different roles, there is also a risk of tension between regulated and commercial roles. While new regulatory frameworks are emerging, it should be noted that they also need to be supplemented with detailed implementation roadmaps and timelines. This gap between regulatory intent and operational execution undermines both trust and investment. Regulators, DSOs, TSOs, and market actors together need to shape clarity not only on what is allowed, but on when and how new rules will be applied. In summary, regulation without clear implementation mechanisms cannot translate ambition into action.

Delivering flexibility at scale requires a coherent regulatory foundation built on clear governance, coordinated implementation, and behavioural realism: a national roadmap and common valuation methodology must guide all system operators, DSOs must be empowered with matching authority and tools, implicit and explicit mechanisms must be aligned, fairness and data transparency must be ensured, and planning models and institutional roles must evolve to reflect how consumers actually adopt, use, and provide flexibility.

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1. Establish a clear national roadmap for flexibility implementation at SO-side

Belgium's regional diversity in flexibility market maturity calls for a coordinated national approach that respects local contexts while preventing fragmentation. Policymakers should define a shared set of *no-regret measures*—such as data access protocols, DSO-TSO coordination rules, and transparency standards—paired with clear implementation milestones. This roadmap should be transparent, time-bound, and adaptable to regional conditions, ensuring that all system operators advance in a harmonised yet context-sensitive manner. A good example is the ENA roadmap between all UK DSOs.

2. Develop a standardized methodology for valuing flexibility

In order to decide which flexibility mechanisms work best in which circumstances, and in order to incentivize consumers, the value of flexibility should be determined in a consistent and uniform way across Belgium. To achieve this, a solid methodology needs to be developed ensuring all regions and actors take similar decisions based on an equal interpretation of the value of flexibility. Energy system models in combination with grid operational models can play a significant role in this process to assess monetary benefits of flexibility.

3. Align governance structures with grid responsibilities

Grid safety is a DSO responsibility, even when flexibility is activated by the TSO. This requires proper prequalification of flexibility assets connected to DSO grids — both for their own markets and for enabling participation in TSO markets. D3.3 shows that without effective coordination, TSO activations can lead to voltage violations or congestion in the distribution network, particularly when grid constraints are not integrated into market clearing. **Grid safety is therefore not just a technical matter—it is a governance challenge.** If DSOs are to be held accountable for local reliability, they must be given proactive roles in market design, bid filtering, and activation sequencing. In addition, they must be allowed to implement preventive approaches—such as prequalification using operating envelopes—which are more reliable than purely corrective mechanisms. However, implementing these measures requires real-time data access and clear regulatory mandates. At the same time, responsibilities and access rights between TSOs and DSOs should be carefully balanced. DSOs may justifiably seek to retain control over distribution-level assets unless appropriate safeguards are in place, or alternatively be empowered with the operational tools and authority to manage such access effectively. Without such alignment, there is a risk of mismatch between responsibilities and capabilities, which could undermine both grid reliability and confidence in flexibility markets.

4. Ensure coherence between implicit and explicit flexibility mechanisms

Uncoordinated interaction between tariffs, market-based services, and NFCAs can cause operational conflicts, undermining both safety and consumer trust. Policy frameworks should be enforced that align implicit (tariff-based) and explicit (market-based) mechanisms under common rules for prequalification, activation sequencing, and redispatching, ensuring they complement rather than compete with each other. This could be done in coordination with system operators, who should be allowed to provide inputs in terms of their needs, processes…

5. Embed fairness and accountability in flexibility governance

Flexibility markets can inadvertently reinforce inequality if not properly safeguarded. Regulation should guarantee transparent pricing logic, enforce non-discriminatory access, and establish robust monitoring systems to detect and correct strategic bidding or market manipulation. A dedicated regulatory function for market monitoring—covering pricing behaviour, liquidity, and concentration—should ensure that flexibility delivers societal value rather than private rents.

6. Strengthen data governance and regulatory observability

ATRIAS, FlexHub, and Elia's Real-Time Coordination Platform are three central data initiatives in Belgium that need to further mature and evolve. Currently, the underlying data models and APIs differ across systems, and governance structures are not aligned. In Belgium, there could be clear value in establishing an overarching coordination layer that connects all three systems — harmonizing governance, access, and architecture. Such a layer could also enable the integration of network and market data across platforms like ATRIAS and FlexHub. Moreover, there is a growing need to promote open standards and make integrated datasets available not only for commercial use by market actors but also for research and innovation purposes.

7. Monitor the uptake of flexible assets and support if needed

Analysis of smart EV charging shows that the economic value of flexibility grows strongly over time, as more electric vehicles and renewable electricity enter the system. Yet, in the early years (around 2030), financial returns for flexibility providers may still be too low to trigger sufficient investment — creating a potential "valley of death" where promising technologies struggle to scale. Temporary policy support or incentives may therefore be required to sustain uptake until flexibility becomes self-sustaining. Similar assessments should be conducted for other flexible assets to understand where and when support is most needed across the energy system.

8. Paradigm shift required in energy system planning models

Distributed resources operated by consumers are not guaranteed to be operated optimally. Energy system planning must evolve to reflect how consumers actually adopt and operate distributed resources. Current models, which assume optimal or uniform behaviour, overlook critical factors such as income, trust, and perceived value that drive uneven participation in flexibility services and DER adoption. Future planning frameworks should embed consumer preferences and behavioural diversity directly within modelling structures—moving beyond scenario-based assumptions toward integrated, agent-based or behavioural approaches. By aligning investment and flexibility planning with real-world adoption patterns, DSOs and policymakers can better anticipate congestion risks, target interventions where flexibility is most likely to emerge, and achieve more efficient, resilient, and socially grounded grid development.

9. Formalise coordination roles and responsibilities

New roles—such as community managers and neutral market operators—must be given formal recognition, legal mandates, and accountability mechanisms. These roles act as bridges between consumers, DSOs, and markets, and should be clearly defined in regulatory structures. Governance frameworks should ensure neutrality, transparency, and standardised interfaces across all flexibility operations.

3.2 Incentives - Understanding the Consumer: The foundation of effective incentives

Flexibility does not arise spontaneously—it must be intentionally designed through incentives that align consumer motivations, market value, and societal goals. Yet, consumers are far from uniform. Their decisions are driven not only by price, but by comfort, trust, control, and perceived fairness. Financial incentives alone are insufficient when intrinsic motivations or risk aversion dominate. ALEXANDER shows that adoption and participation are shaped by behavioural diversity: consumers heavily discount future savings, respond strongly to upfront benefits, and rely on trust to engage in managed services. Incentive structures must therefore be predictable, transparent, and tailored to real human behaviour. ALEXANDER's behavioural research reveals that understanding consumer preferences is not an optional add-on—it is the foundation for effective incentive design. Consumers differ in what they value, how they perceive risk, and the level of trust they have in the system. Without recognising this diversity, policies risk underperforming or excluding large parts of society.

Incentive design must start from the consumer. Both explicit and implicit incentives are needed, supported by stable, transparent frameworks that reward real participation and reflect behavioural diversity. The value of flexibility must be clear, immediate, and fair for every actor.

1. Recognise intrinsic motivations alongside financial ones
Intrinsic drivers—like environmental concern, desire for autonomy, and community belonging—often outweigh financial motives. Programs that emphasise self-sufficiency, green energy use, or collective benefit can activate flexibility even when direct financial rewards are modest. Regulators and aggregators should frame flexibility as a consumer-centric service that protects comfort, provides autonomy, and contributes to shared sustainability goals.

2. Account for the 'flexibility discount rate gap'
ALEXANDER finds that high upfront costs and delayed benefits are major barriers to household adoption of DERs and flexibility technologies. Consumers respond more strongly to incentives that provide direct financial relief at the point of purchase or clearly quantifiable savings early in ownership. Policymakers should structure incentives to reduce upfront investment—such as smart charging rebates or PV/battery grants—or to bring forward benefits through accelerated payback mechanisms, ensuring that value is tangible from the outset and adoption rates increase across income groups.

3. Use tariff and pricing structures strategically
Different tariffs influence different technologies. Capacity-based tariffs promote home battery storage, while volumetric tariffs favour PV adoption. Policymakers should use tariff design as a deliberate lever to steer balanced DER adoption that maximises system-level flexibility. Transparent, moderately granular pricing (e.g. 3–6 hourly) captures most benefits without creating consumer confusion or volatility.

4. Tailor incentives to consumer segments
Demographics, routines, and infrastructure access strongly shape participation. Younger, higher-educated, and tech-familiar users respond differently from older or lower-income households. A segmentation-based approach is more efficient and equitable than universal measures. Target the receptive 80% in early phases to maximise impact, while designing adapted schemes for the remaining 20% through simplified participation, community pooling, or shared-ownership models. Socio-economic disparities mean that not all households can invest or take on risk equally. Policies should combine differentiated financial support with simplified procedures and communication designed for low-trust or low-literacy groups. Regulatory design should prevent flexibility markets from concentrating benefits among higher-income, more digitally literate participants.

5. Reframe flexibility as a customer-centric service that protects comfort, builds trust, and delivers visible value
ALEXANDER finds that behavioural barriers such as range anxiety, distrust in savings, and perceived loss of control limit participation in flexibility programs. To overcome these, market actors should design offerings that embed regulated service guarantees (e.g., minimum EV battery levels, temperature safeguards, emergency support) and intuitive platforms with transparent activation criteria, opt-in service levels, and clear manual override options. Flexibility should be bundled with tangible, high-value benefits (such as lower upfront costs, solar self-consumption optimisation, or mobility guarantees) and aligned with intrinsic motivators like autonomy, environmental impact, and community benefit. Regulatory frameworks must enable bundled service models, remove barriers to innovation, and support interoperability so solutions work seamlessly across devices and platforms.

Through targeted pilots, visible feedback, and segmentation by user profile, flexibility can be repositioned from a technical constraint into a trusted, desirable part of everyday energy and mobility services.

6. Harmonise incentives across DERs
ALEXANDER finds that misaligned incentives—such as policies favouring PV adoption without equivalent support for batteries or smart charging—limit the system-level flexibility potential of household investments. When tariffs, subsidies, and regulatory frameworks vary significantly across DER types, consumers are less likely to adopt complementary technologies, reducing the value of their contributions to grid stability. Policymakers should align incentives to encourage bundled DER adoption and coherent investment decisions, ensuring that households are rewarded for integrated solutions that maximise flexibility, optimise self-consumption, and reduce system costs.

7. Build and protect institutional trust
Trust in the actor managing flexibility—be it a retailer, aggregator, or community manager—determines whether consumers are willing to delegate control. Regulators should enforce transparency, ensure oversight of intermediaries, and communicate continuity in policy schemes. Abrupt policy shifts, as seen in past PV support changes, erode trust and slow adoption. Stable, pre-announced policy roadmaps are essential (see also further).

8. Announce and communicate incentives well in advance to shape consumer decisions
Households make investment decisions around policy timing. Early, transparent announcements of subsidy changes or tariff reforms prevent volatility, build confidence, and allow markets to plan. Some sort of "Anticipatory consumer market design roadmap" should also provide long-term, credible insights into incentives schemes, tariff reforms, smart meter roll outs... avoiding abrupt policy reversals or poorly communicated phase-outs. In addition, one should pre-announce major changes and conduct stakeholder outreach in advance to stabilize expectations and allow users to plan. A stable policy environment builds confidence and accelerates adoption. Policy uncertainty erodes flexibility potential and system legitimacy. This approach increases trust, encourages orderly market growth, and avoids last-minute surges that can strain supply chains or grid capacity.

9. Design markets to enable safe value stacking from the start
ALEXANDER finds that aligning market timings, products, and procurement decisions across DSOs, TSOs, and wholesale markets allows flexibility assets to stack value across services, boosting both FSP revenues and system efficiency. Policymakers should set clear rules for bid forwarding, free unused bids for other markets, and ensure transparent information sharing between operators.

3.3 Communication and knowledge sharing: From regulatory diversity to collective learning

Flexibility requires collaboration across many actors—consumers, DSOs, TSOs, aggregators, and policymakers—yet their perspectives and vocabularies often diverge. Regulatory diversity between regions and sectors compounds confusion, while limited public awareness and low trust hinder participation. ALEXANDER finds that transparency, consistent communication, and shared learning are the connective tissue of a successful flexibility ecosystem. Effective communication is not just about outreach—it is about building understanding, credibility, and coordination capacity across the entire energy chain.

Regulatory and market diversity must be addressed through structured collaboration and shared knowledge. Building collective understanding—between regulators, operators, and consumers—is as critical as technical alignment. Collaboration, awareness, and transparency are the foundations of trust and coordinated action.

1. Build trust through transparent, relatable communication

Building trust and countering misinformation and fear, is essential for large-scale household flexibility. DSOs, retailers, and aggregators must embed transparency, fairness, and autonomy into every program, using behavioural insights to deliver visible value and user control. Consumer trust is the operational foundation of flexibility. Communication, demonstrations and awareness campaigns must move beyond technical jargon to focus on relatable value propositions—comfort, savings, autonomy, and contribution to community goals. Trusted messengers, such as local energy communities or public institutions, should lead information campaigns that simplify choices and clarify rights and benefits. However, it should be noted that building trust also depends on plain-language contracts, transparent pricing, and strong consumer protection frameworks that ensure reliability, accountability, and simple, value-based communication. Additionally, actors should establish clear standards for transparency and fairness in retailer- or aggregator-led programs by ensuring transparent pricing logic, plain-language contracts, and robust privacy protections; strengthen consumer protection frameworks to go beyond billing accuracy and address service reliability, proactive communication, and accessible, trustworthy complaint resolution; define and enforce accountability for third parties controlling user devices or behaviours to align decisions with both consumer welfare and system needs; and deliver proactive, tailored communication in relatable, value-focused terms that avoid technical jargon.

2. Institutionalise awareness and education programs

Targeted education and awareness campaigns are crucial to counter misinformation and demystify new technologies. Policymakers should embed these efforts in national energy strategies, focusing on tangible user concerns (e.g., range anxiety, privacy, comfort). Demonstration projects and peer-to-peer learning platforms can translate abstract concepts into lived experience.

3. Reinforce structured knowledge-sharing frameworks between regions and actors

Belgium's split responsibilities across regions and across regional and federal levels, calls for a national knowledge-sharing platform that connects DSOs, TSOs, regulators, and aggregators. Shared case studies, open datasets, and technical workshops can align implementation practices while allowing for contextual diversity. Regular interregional reviews should benchmark progress and identify transferable lessons.

Belgium's regional structure requires stronger national coordination between DSOs, TSOs, regulators, and aggregators. A shared platform with open datasets, common case studies, and regular technical workshops can help align implementation practices while respecting regional differences. Cooperation should not stop at the implementation of specific directives. Regions and actors should also work together on joint research projects and shared roadmaps. Building knowledge together from the start makes it easier to stay aligned later when policies are turned into action.

4. Promote cross-domain collaboration

Siloed expertise delays system integration. Policymakers should establish early cross-domain working groups bringing together technical, economic, and behavioural experts. These groups can co-design pilots, ensure interoperability between systems, and generate feedback loops that inform regulatory updates and investment planning.

5. Communicate policy continuity and coherence
Historical instability in incentive programs has eroded public confidence. Communication should clearly convey long-term intent and sequencing of policies. Policy changes must be pre-announced and explained consistently across agencies, ensuring households and market actors understand how new rules interact and evolve. As indicated previously: a clear consumer roadmap with transparent timelines and steps would facilitate this point a lot.

3.4 Tooling and Infrastructure: Enabling the System to Deliver Flexibility

Infrastructure is the enabler that turns policy ambition into operational capability. DSOs, TSOs, and aggregators cannot manage flexibility safely without observability, data access, and interoperable digital tools. Consumers cannot participate effectively without enabling infrastructure—smart meters, connectivity, and installation services. ALEXANDER demonstrates that infrastructure deficits are now among the main bottlenecks for flexibility deployment. Without real-time data, predictive tools, and coordination platforms, even well-designed markets remain inert.

Infrastructure must be built out across the full chain: consumers need enabling access and tools, DSOs need visibility and operational control, and regulators need robust monitoring systems. Investment in digital, physical, and analytical infrastructure is the backbone of a functional flexibility ecosystem.

1. Invest in grid observability to enable proactive congestion management
ALEXANDER finds that without sufficient local visibility, DSOs cannot accurately assess the impact of flexibility activation or address emerging constraints before they escalate. Advanced tools such as the ALEXANDER Congestion Forecaster can improve LV network observability, accounting for unique challenges like limited measurement availability, and enable DSOs to predict and manage congestion proactively. Policymakers and regulators should prioritise investment in measurement infrastructure, smart meter data integration, and forecasting tools that provide real-time or forward-looking insights. These insights should be shared with all stakeholders to build transparency on actual and future grid needs, guide targeted deployment of flexibility mechanisms, and inform where technical upgrades or investments are most needed. Strengthening observability in this way reduces reliance on costly corrective actions and ensures flexibility activation supports, rather than risks, grid stability.

2. Prioritise preventive, ideally dynamic, grid-safety measures over reactive corrections
ALEXANDER finds that preventive grid-safety mechanisms—implemented before or during procurement—are more reliable and cost-effective than ex-post corrections, particularly in stressed or low-liquidity markets. Dynamic, operating-envelope-based prequalification enables precise, real-time alignment of bids with actual grid conditions, maximising participation without compromising safety, but requires investment in data quality, ICT infrastructure, and strong TSO–DSO coordination. Where feasible, bid aggregation can achieve near-optimal efficiency while preserving grid-data privacy, offering a practical pathway for fragmented systems to coordinate flexibility procurement. Policymakers and system operators should integrate these approaches into market processes to ensure grid security, maximise liquidity, and optimise the use of distributed flexibility resources.

3. Design non-firm connection agreements (NFCAs) to balance grid safety, market reliability, and fairness
While NFCAs can safeguard local grids and expand flexibility availability, uncoordinated activation risks conflicting with market commitments, and location-based restrictions can create unfair outcomes.

Policymakers should ensure NFCAs are coordinated with market operations and incorporate fairness (e.g., no locational discriminatory), even if this slightly reduces total available capacity, to maintain trust and participation.

4. Match grid-safety mechanism complexity to market maturity and grid stress levels
In early-stage or low-stress markets, simpler methods like static prequalification can lower entry barriers, while more advanced markets with high DER penetration require dynamic operating envelopes or full network representation. Regulators should set phased implementation pathways based on system conditions. Furthermore, regulatory review on grid-safety mechanisms is important as DER penetration evolves. What is effective under current DER adoption rates may become inefficient or unsafe as market volumes grow. Regulators and SOs should embed periodic reviews into market design, adjusting prequalification rules, price caps, and coordination protocols accordingly.

5. Benchmark market price caps against non-market alternative costs
ALEXANDER finds that grounding price caps in the actual costs of alternative grid solutions prevents excessive rents and strategic manipulation in early-stage markets. Regulators should mandate transparent, cost-based caps to protect efficiency and public trust.

6. Implement robust market monitoring mechanisms to mitigate strategic behaviour
To detect and deter strategic behaviour in flexibility markets, regulators should mandate systematic collection and analysis of market transaction data. These monitoring mechanisms aim to detect, assess, and address potentially harmful strategic behaviours in the market through a multi-dimensional monitoring approach. This includes tracking overall market conditions and performance, such as supply-demand balance, price levels, bid sufficiency, product market costs, and price-cost markups, benchmarking actual prices against long-run competitive market estimates to identify market power, and analysing individual bidding and scheduling behaviours relative to historical patterns. When harmful strategic bidding is identified, enforcement actions may be taken, ranging from fines and cost-based remuneration to temporary or permanent bans on the involved unit.

7. Deploy integrated IT/OT systems for TSO–DSO–FSP coordination
Integrated digital platforms are required to align grid operations and market transactions. DSOs and TSOs should jointly invest in interoperable systems that combine network data, market activation signals, and settlement information. Open, secure APIs must enable real-time validation and coordination of flexibility activations.

8. Adopt and enforce data exchange standards
Interoperability requires uniform data standards for message formats, validation workflows, and security protocols. Regulators should mandate a national standard for data exchange across DSOs, the TSO, and market participants. This reduces integration costs and ensures seamless coordination between flexibility platforms and grid management systems.

9. Establish a centralised data access hub
A centralised, standardised data hub should provide transparent access to DER and flexibility-related data, while ensuring privacy and role-based permissions. This should include data on PV, heat pumps, EVs, and behavioural indicators, as well as representative smart meter datasets to support evidence-based policy evaluation and potentially also grid information. Today, initiatives like ATRIAS and FlexHub are mostly focusing on data linked to market processes between suppliers, SOs and other market players, or are exchanging specific flexibility data. However, as indicated, these data could be extended, combining further data on assets or grids, household energy performance statistics, and further consumer characteristics to be able to improve forecasting models etc.

10. Equip community managers and market operators with analytical tools
Community managers need real-time monitoring, forecasting, and pricing tools to balance member needs and grid constraints. Market operators must be equipped with modular, interoperable platforms capable of managing bid aggregation and multi-level coordination. Policymakers should prioritise pilot programs that test these tools under diverse grid and market conditions.

11. Invest in enabling infrastructure for equitable participation
Physical and digital access gaps—such as EV charging networks, broadband connectivity, or installer capacity—can prevent motivated users from contributing flexibility. Targeted investment in underserved areas ensures that participation opportunities are available to all consumer groups, preventing regional or socio-economic exclusion.

3.5 Future Research and Development: Keeping the System Adaptive

Flexibility is not a static capability—it evolves with technology, consumer behaviour, and market design. Continuous learning, experimentation, and model refinement are vital to maintain realistic and fair flexibility integration. ALEXANDER underscores that current models often overestimate flexibility by assuming rational, homogeneous consumers, while underestimating behavioural and contextual barriers.

Research and development must remain a permanent function of flexibility governance. Continuous learning through pilots, behavioural observation, and model validation is essential to ensure that policy and markets reflect real-world complexity.

1. Integrate behavioural realism into system models for adequacy and balancing
Energy system models should incorporate bounded rationality and consumer diversity, using stochastic or agent-based approaches calibrated with real-world data. This ensures forecasts and remuneration structures align with actual consumer decision-making patterns.

2. Validate assumptions through field experiments
Move beyond stated preferences to observed behaviour. Field trials and pilots should test incentive structures, service guarantees, and market coordination tools under real-life conditions, capturing behavioural responses that models cannot predict.

3. Maintain an early and iterative feedback loop between research and implementation
Insights from pilots and consumer studies must feed directly into regulatory updates, system planning, and market rules. A permanent research–policy interface should ensure flexibility governance remains adaptive, data-driven, and trusted.

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Annex A: Key Exploitable Results

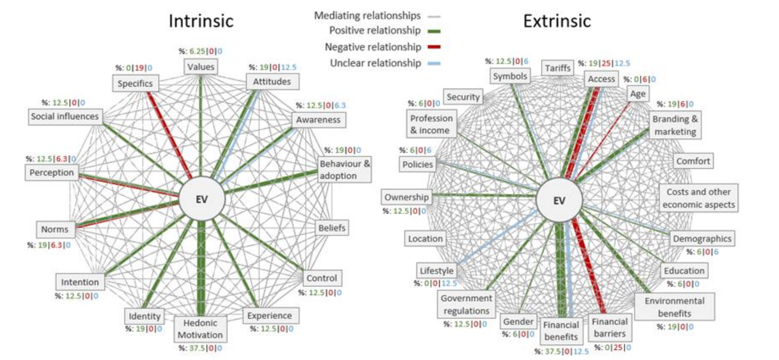
3.5.1 KER 1: Identification of consumer characteristics to unlock low voltage flexibility.

Problem

With the uptake of new DER and facilitating regulation, the role of consumers shifts from passive to active participants in the energy system, enabling consumers to contribute to LV flexibility. It is therefore important to integrate this consumer flexibility in different types of models. However, today, models to assess security of supply and mechanisms for operational flexibility procurement and activation consider consumers as a homogeneous group without considering specific preferences of heterogeneous consumers, and driven by rational, utility-maximising decision processes. This assumption of homogeneous, rational prosumers may be a poor description of reality as they do not have identical motivations nor do they always behave rationally. This might lead to a gap between theoretical potential and the practical flexibility capacity.

ALEXANDER solution: A literature review combining aspects of economic incentives, technical feasibility, and social behaviour was performed to define:

- A use cases methodology: a framework for mapping possible use cases for flexibility in the low voltage electricity system [11]
- Consumer acceptance technologies framework suggesting that psychobehavioural variables such as norms, hedonics, and control may play a more important role than extrinsic factors in the adoption of different technologies [12].
- Consumer characteristics for flexibility provision revealing a set of factors that commonly affect the provision of demand-side flexibility in residential environments, which were classified into intrinsic, extrinsic, and routine-related categories.



Adoption factors for Electric vehicles (EV)

Contribution to ALEXANDER objectives

- Understand consumer preferences – considering the heterogeneity and not always rational behaviour
- Insights in heterogenous and bounded-rational behaviour of end consumers allowing a better representation and exploration of the LV flexibility in different models.
- Indirect contribution to grid stability, renewable energy participation, CO_2 neutrality, and economic welfare through consumer flexibility profiling, market participation frameworks, and policy recommendations.

How can DSOs benefit?

DSOs will have better insights into consumer flexibility potential to maintain grid stability while integrating renewable energy sources and electric mobility solutions.

How can TSOs benefit?

Insights into the flexibility potential of LV consumers will support Elia in balancing the supply and demand. All system operators benefit from insights into consumer behaviour and flexibility provision, helping to design incentives and mechanisms for demand-side flexibility integration.

How can policymakers benefit?

The result offers evidence-based guidance to refine regulatory frameworks for energy communities, aggregators, and prosumers, ensuring alignment with Belgium's transposition of the Clean Energy Package.

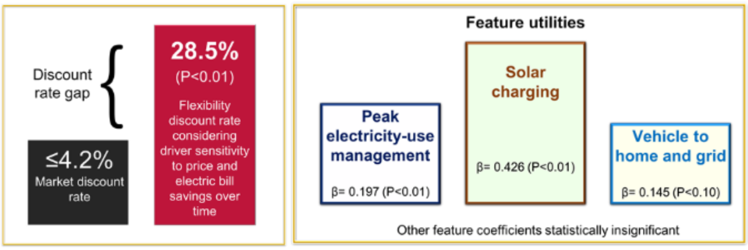
3.5.2 KER 2: Driver Preferences for Investment in Flexible Electric Vehicle Charging

Problem

The EU will ban the sale of conventional petroleum-powered vehicles by 2035[36]. For Belgium, there is an obligation for company cars to be electric starting from 2026 onwards [37]. This transition raises concerns about increased electricity demand, particularly during peak hours when unmanaged charging behaviour could put significant strain on the electric grid and increase the risk of disruptions. This risk can be avoided if drivers provide different types of flexibility. The success of EV flexibility in large part depends on user participation. Assuming full or uniform participation, without accounting for user preferences, risks misjudging EV's flexibility potential.

ALEXANDER solution: Discrete Choice Experiments (DCEs) were used to elicit Belgian preferences on flexible EV charging:

- drivers place much more weight on immediate costs than on delayed financial benefits,
- expectations about future electricity pricing (time-of-use tariffs and rising per-kWh rates) are associated with a greater willingness to adopt flexible chargers,
- willingness for solar charging, dynamic load management, and V2HG charging.
- range anxiety is a significant barrier to flexible EV charging



Contribution to ALEXANDER objectives and impact

- Understand consumer preferences – DCEs were used as a methodology for quantifying how Belgian consumers value incentives to participate in smart charging, identifying financial and psychological adoption barriers
- Climate & energy transition – Smart charging of EVs enables smoother integration of renewables and electrified loads, supporting CO_2 neutrality.
- Economic welfare – Considering user preferences in smart charging of EVs contributes to providing LV flexibility which might decrease investment costs in the grid and save additional costs for consumers.
- Security of supply and system balancing – through increased participation in flexible EV charging by identifying the financial and psychological barriers to managed bidirectional charging
- New insights in heterogenous behaviour of consumers - make it possible to incorporate heterogeneous consumer behaviour and governance preferences into simulations and scenario planning.

How can TSOs benefit?

Understanding user willingness to participate in such programs is important for both short-term balancing and long-term system adequacy.

How can DSOs benefit?

Insights into which flexibility services Belgian drivers are most willing to adopt can inform strategies to defer costly grid upgrades and enhance local grid resilience.

How can energy retailers benefit?

Energy retailers can boost engagement by bundling energy supply with home and EV charging, acting as aggregators to align customer value with grid needs.

3.5.3 KER 3: Survey design to analyse the influence of individual consumer characteristics and governance approaches on their engagement in collective flexibility concepts

Problem

Energy Communities (ECs) can be seen as a means to empower local energy users and accelerate adoption of renewable energy. Most existing research focuses on financial or technical incentives. While economic and technical incentives are undeniably central to encouraging participation in ECs, they do not fully account for the social and institutional dynamics that shape consumer engagement. ECs face several operational challenges, including the difficulty of recruiting and retaining participants, the absence of standardized approaches for organizing collective energy sharing, and limited understanding of how consumers respond to different governance models

ALEXANDER solution: A survey framework was developed to explore how governance structures, decision-making processes, and community benefits influence consumer participation in ECs. Specifically, it provides the design of two Discrete Choice Experiments (DCEs) [38] (including choice context, attribute list, and sample choice cards) that can be used to build surveys exploring how governance-related features such as decision-making, benefit-sharing, and transparency influence engagement of consumers in ECs.

Attribute	Option 1	Option 2	Status Quo
Time of Engagement	5 p.m.–8 p.m.	10 a.m.–1 p.m.	No engagement in Load Shifting Contracts
Frequency	Occasionally (Once a week)	Frequently (Several times a week)	
Load Reduction	15%	20%	
Grid Emission Reduction	10%	10%	
Participation Opt-out	Daily window of 1 hours	Daily window of 2 hours	
Remuneration per Year	150€	40€	

Contribution to ALEXANDER objectives and impact

- Climate & energy transition - Facilitating greater participation in collective self-consumption and local renewable energy use contributes to the decarbonization of the energy system
- New approach to understand consumer preferences - providing a ready-to-use framework for assessing how different governance and participation models affect engagement in ECs
- Consumer preferences - assessing consumer engagement in demand-side flexibility and ECs, developed through a DCE framework
- New insights in heterogenous behaviour of consumers - making it possible to incorporate heterogeneous consumer behaviour and governance preferences into simulations and scenario planning.

How can researchers, consultants, and analysts benefit?

These actors require practical tools to explore how governance structures and decision-making processes influence participation in ECs, an area that remains understudied in Belgium. Especially since these institutional features shape trust, perceived fairness, and willingness to engage — all of which are critical for the success of collective flexibility initiatives.

How can policymakers, energy cooperatives and aggregators benefit?

In the longer term, the insights generated from such applications would benefit policy makers who are responsible for shaping legal frameworks that support citizen participation in energy systems. Local governments, energy cooperatives, and aggregators may similarly apply the findings to design more inclusive and effective energy initiatives that align community values with flexibility needs.

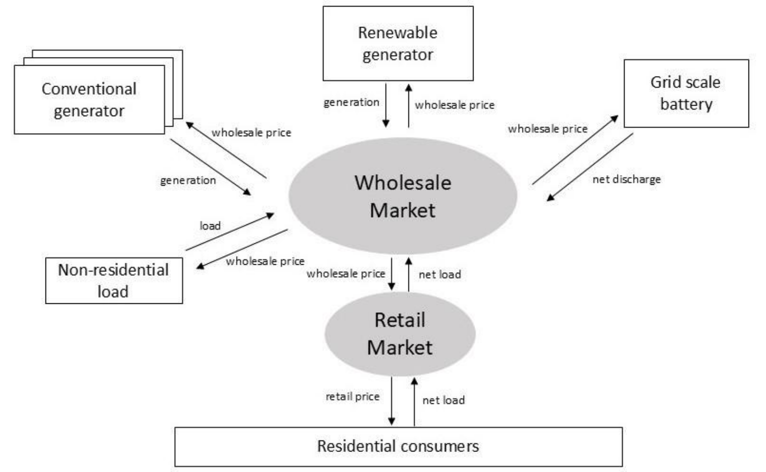
3.5.4 KER 4: System-wide benefits of temporal alignment of wholesale–retail electricity prices

Problem

Due to the more active participation of prosumers, aligning retail electricity prices with wholesale prices by including temporal variation is often seen as beneficial to the energy system. However, a high level of price granularity requires significant household participation which might be complex. Therefore, it is important to assess whether a lower level of temporal granularity is a good compromise of sufficiently aligning retail and wholesale electricity price patterns and reducing the degree of involvement of household participation. Also, it is crucial to understand whether these price levels incentivize the uptake of PV and home batteries for households but also whether the overall Belgian energy system benefits from such a level of temporal granularity through an overall reduction in the costs, taking into consideration different types of distribution tariffs (fixed rate, volumetric tariff or capacity tariffs).

ALEXANDER solution: By using a simulation model we gained the following insights [15]:

- Gains from real time pricing are not so significant in comparison to three- and six-hourly electricity pricing schedules for households
- In general, a higher level of granularity allows households to react to market prices by adjusting consumption patterns (demand response) and providing flexibility through (dis)charging of home batteries.
- Volumetric and capacity-based distribution tariffs erode price signals and cause inefficiency



Contribution to ALEXANDER objectives

<u>Climate & energy transition</u> - flexible pricing schemes can provide significant gains to the overall energy system by lowering its cost and hence help reduce the cost of the energy transition.

<u>The heterogeneity of end-consumers</u> - new evidence that the different pricing schemes for households can affect consumer costs differently and influence consumer investment decisions

How can DSOs benefit?

The study offers insights into the interplay between different levels of flexible pricing and various types of distribution tariffs.

Also, the study provides insights into the effect of distribution tariffs on the uptake of batteries and PV and the implications on the overall system cost for different levels of temporal granularities

How can regulators and retailers benefit?

These results can help foster the dialogue between regulators and retailers on ways to price end-consumers. Regulators could, for example, provide a framework on what level of temporal granularity of electricity prices should be offered to households

3.5.5 KER 5: Assessing the impact of financial benefits on household PV adoption in Belgium

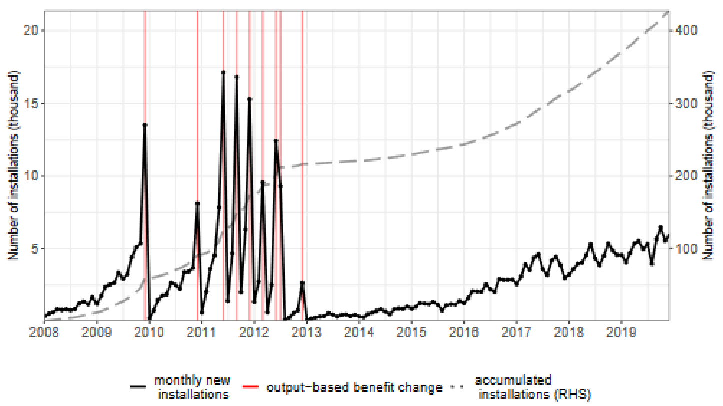
Problem

Renewable energy is essential to achieve climate goals. The Belgian contribution to the European target is expected to amount to a renewable share of 21,7% in 2030 [39]. To achieve these ambitious climate goals the contribution of households to install RES must increase, and a better understanding of how households respond to financial benefits is therefore required. In the case of PV, incentives that stimulate installations have been removed in Belgium and dynamic price contracts further increase uncertainty about the financial benefits of PV adoption at the time of investment. It is important to understand how uncertainty affects household investment in energy-related technologies.

ALEXANDER solution: An assessment of how households have responded to different incentive schemes implemented in Flanders and Wallonia over the past 15 years indicates that [16]:

- The uptake of PV installations in the regions coincides with pre-announced changes in the incentive schemes, suggesting that households are quite sensitive to financial benefits.
- Households prefer benefits in the form of electricity produced (output-based) or installed capacity (capacity-based) to cost savings through the electricity price (net metering).
- Low-income municipalities tend to have lower adoption rates for the same level of financial benefits, but increasing the salience or certainty of benefits can reduce the adoption gap with the remaining municipalities.

(a) Flanders



Contribution to ALEXANDER objectives and impact

- Understand consumer preferences and insights on heterogenous behaviour - improve understanding of household's decision making for specific technologies
- Increase level of RES - the findings can be used to promote the uptake of energy-related technologies such as PV panels, heat pumps or EVs

How can policymakers benefit?

The results are particularly useful for policymakers, specifically the regional and federal government agencies responsible for energy policy, given the ambitious policy goals that require a rapid energy transition and the uptake of renewable energy. The insight gained into PV can be extended to other RES such as EV, heat pumps, etc.

How can DSOs benefit?

DSOs like fluvius, ORES, RESA and Sibelga may benefit from the results as they show that technology adoption can be quite volatile, is dependent on financial benefits in general, and varies by household income.

The results may have implications for identifying future bottlenecks in network investment

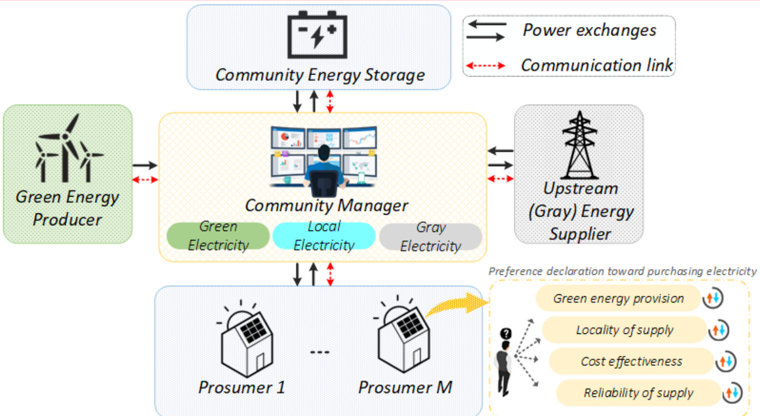
3.5.6 KER 6: A Preference-Informed Energy Sharing Framework for a Renewable EC

Problem

An EC requires internal community distribution keys to divide the energy within the community among its members. Today, in all Belgian regions, the community chooses one distribution key which is implemented at a fixed price. However, experiments indicate that consumers care about more than just price. They also value aspects like how green and local the energy is, as well as reliability and social equity. Accounting for these elements is important, as it could improve users' satisfaction and system optimization. Nevertheless, heterogenous socio-economic preferences of community users are often neglected, in most cases simply because there is no knowledge on user preferences to align energy supply with consumer preferences.

ALEXANDER solution: A comprehensive framework for EC was developed and encompasses [17]:

- A user-friendly methodology that quantitatively captures individual community members' preferences towards different energy products,
- An approach enabling community managers to differentiate and prioritize energy products according to community members' socio-economic preferences,
- A bilevel optimization tool to determine optimal internal pricing and energy exchanges between community manager and prosumers,
- A uniform and innovative pricing mechanism explicitly designed for EC, reflecting commodity and grid costs and user preferences



Contribution to ALEXANDER objectives and impact

- Economic welfare - Incorporating users' energy-preference utility measurably improves welfare, aligning allocations with individual priorities and raising net benefits under community pricing.
- Capturing the heterogeneous consumer behaviour - Quantitative insights into community members' preferences. Results showed 11.1 kW (≈9%) green energy use and 3.27 kg CO_2 savings, confirming diverse user behaviours.
- Improved representation of flexibility among the users – Building block to quantify the impact of LV user preferences on providing flexibility to the system, showing a 12% change in social benefits under PV uncertainty and adaptive energy-source switching.

How can Community Managers benefit?

Community managers, a potential new emerging actor which could contribute to the operational management of communities, will be provided with a practical framework for better aligning energy distribution with user preferences, improving community's utility and engagement.

How can consumers benefit?

This work is a step in the direction of further increasing social welfare through explicitly accounting for consumer preferences.

How can DSOs benefit?

User preferences can play a decisive role in determining the community's baseline consumption and the flexibility envelopes offered to the DSO.

3.5.7 KER 7: On the limited observability of energy community members

Problem

This KER responds to a pressing challenge faced by low-voltage energy communities: the gap between how people are expected to behave in economic models and how they actually behave in daily life. Traditional models assume that users are fully rational, always informed, and able to optimize their consumption according to dynamic internal prices. Yet, community members make decisions under bounded rationality — with limited information, time, and capacity to interpret complex signals. Price signals themselves are only partially visible, as they depend on the simultaneous behaviour of other members, making them harder to anticipate or trust. On top of this, the intermittency of solar PV generation introduces another layer of uncertainty, creating volatility in local energy availability and costs. These combined factors lead to mismatches, inefficiencies, and perceived unfairness, threatening the smooth operation and acceptance of dynamic energy sharing.

ALEXANDER solution: a new uncertainty-aware energy sharing framework [18]:

- A new internal electricity price as a decision tool that guides community members to adjust their energy use more effectively.
- Modelling realistic user behaviour by accounting for the limited visibility of internal prices and imperfect optimization patterns that real people have
- Mitigating solar variability via stochastic optimization of PV generation projections
- Bilevel programming framework that optimizes along two layers:
    - The community manager sets internal prices and energy sharing rules
    - The community members respond to these prices by making realistic energy consumption decisions

Contribution to ALEXANDER objectives and impact

- Understand consumer preferences – provides insights into the impacts of bounded rationality on predicting consumer behaviour
- Insights in heterogenous and bounded-rational behaviour of end consumers – quantifies the impact of bounded rational behaviour on flexibility provision by system actors like DSOs
- Social and Economic welfare – accounting for realistic user behaviour allows members to benefit not only financially, but also more fair and transparent, boosting trust and satisfaction.

How can Community Managers benefit?

The effective coordination of the community can facilitate internal exchanges with community members and external exchanges to electricity suppliers.

How can Community Members benefit?

The framework helps community members handle the uncertainties that arise from dynamic electricity prices and intermittent PV generation.

How can DSOs benefit?

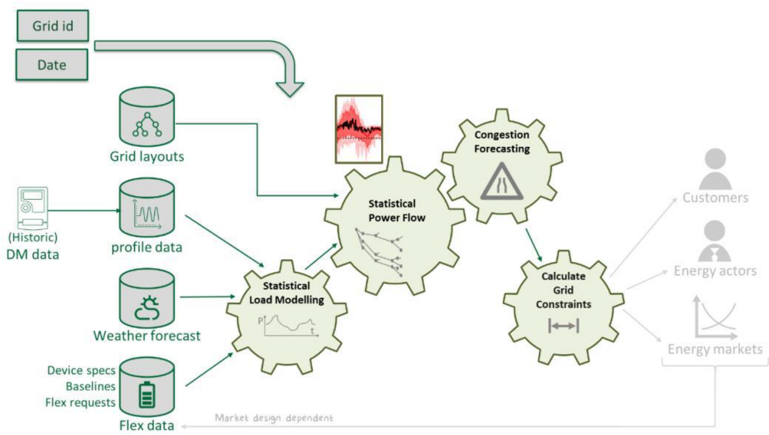
The improved decision-making of communities' results in a reduction of peak load consumption and reliance on external energy suppliers which could improve network conditions if done at the right time.

3.5.8 KER 8: LV congestion forecaster

Problem

DSOs have a very low level of observability in their LV network. Indeed, parts of the LV network are (almost) not measured nor monitored automatically, and as a result, it is hard to forecast what is likely to happen on the networks. Nevertheless, having a better view of LV networks is necessary for DSOs to be able to manage their assets better. The latter would lead to improved asset use and eventually lower costs for society. Furthermore, before DSOs can acquire flexibility, they need to know where the congestion risks are, and thus, the needs for congestion management in their LV networks. Currently, the lack of measurements in LV grids makes it hard to estimate congestion risks, making it hard to further improve distribution grid management.

ALEXANDER solution: The LV congestion forecasting tool aims at calculating the risks for congestion on a LV distribution feeder for a forecasted day. The tool does not deterministically calculate congestions, as for this calculation the necessary input would be impossible to acquire (e.g. deterministic forecasts of single connection consumption are not available) but merely outputs a congestion risk based on the statistically possible LV feeder states during the forecasted period. The calculations within the tool are based on historical, and (if available) recent, grid and connection profile measurements, as well as weather forecasts.



Contribution to ALEXANDER objectives

- New operational models and algorithms for future proof active system management that allow cost-efficient flexibility procurement and activation in a grid safe and coordinated way
- Security of supply and balancing - better network insights allow DSOs to safely activate more flexibility, improving grid balancing and ancillary services.
- Climate & energy transition - Proactive congestion management enables smoother integration of renewables and electrified loads, supporting CO_2 neutrality.
- Economic welfare - Targeted investments reduce unnecessary costs, lowering tariffs and boosting economic welfare for everyone.

How can DSOs benefit?

The congestion forecaster & grid constraints calculation module are designed such that:

- The highly statistical behaviour of load is inherently considered, and includes the influence of external parameters, such as weather data.
- It is not required that all loads are extensively measured, nor that the DSO has access to extensive user data.
- Grid layout is assumed to be known; however, it is taken into account that the exact phase connection of single-phase loads is not always known.

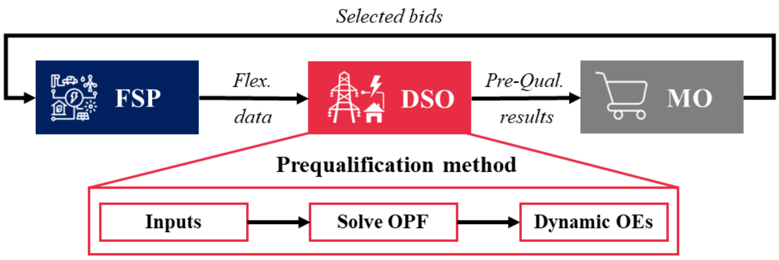
These characteristics lead to a tool that can be exploited within the current DSO environments as they exist today within Europe with different regulations on which information can or cannot be used by DSOs due to GDPR rules, among other constraints.

3.5.9 KER 9: Dynamic grid (pre-)qualification using operating envelope

Problem

Any flexibility resources, either located in transmission or distribution networks, can participate in balancing markets. However, such markets typically do not take into account distribution grid operation when selecting distribution-level flexibility resources, potentially resulting in unsafe activation of these resources (i.e., causing local network issues, such as congestion). On the other hand, the electrification of industries and small-scale consumers opens up significant potential for low-voltage flexibility resources to participate in balancing markets. Therefore, grid-safe participation and activation of distribution-level resources in a system-wide flexibility market, such as a balancing market, must be ensured.

ALEXANDER solution: The ALEXANDER grid (pre-)qualification tool calculates allowable limits of distribution-level flexibility resources (operating envelopes) such that any activation of these resources within these limits does not cause local grid issues, such as congestion and voltage violations. To that end, tailored optimal power flow problems (OPFs) must be solved relying on a network model. The tool is suitable for typical medium voltage distribution grids with a radial structure. The limits can be updated dynamically based on the current states of the network, thus appropriately limiting flexibility without unnecessarily blocking flexibility resources in market participation.



Contribution to ALEXANDER objectives

- New operational model for future proof active system management – allowing cost-efficient flexibility procurement and activation in a grid way. Versatile (pre-)qualification tool that is performed dynamically based on the most up-to-date states of the network.
- Security of supply and balancing - Improving the efficiency of market-based flexibility provision for balancing by allowing the participation of distribution-level flexibility.
- Climate & energy transition - Distribution-level flexibility resources include solar-based generation, batteries, flexible loads, and electric vehicles. By allowing these resources to participate in a flexibility market, the tool helps the integration of these resources into the existing energy ecosystem.
- Economic welfare - Increasing participation in flexibility markets can help reduce clearing prices, which will improve economic welfare.

How can DSOs benefit?

The operating-envelope-based prequalification tool ensures that their grids are safely operated when flexibility resources located in their grids are cleared by a balancing market and subsequently activated. In addition, it further increases flexibility potential by taking away more stringent market access barriers. Therefore, DSOs do not have to worry about resolving any possible local grid issues due to this activation.

How can TSO benefit?

The efficiency of a balancing market can improve when the pool of resources enlarges by safely incorporating distribution-level resources.

How can FSPs benefit?

Optimal prequalification methods ensure unnecessary blocking of flexibility, increasing options for FSPs to offer their flexibility.

3.5.10 KER 10: Utilization of Operating Envelopes in Non-Firm Connection Agreements (NFCAs)

Problem

LV grids face rising stress from renewables, EVs, and flexible household devices. To prevent congestion, DSOs can use Non-Firm Connection Agreements (NFCAs), which temporarily limit users' consumption or production. While effective for grid safety, NFCA activations can block pre-qualified LV assets, such as batteries or EVs, from delivering contracted services in system-wide markets. This creates a conflict between local network protection and system-level flexibility needs, risking reliability, market efficiency, and trust in LV assets.

ALEXANDER solution: ALEXANDER shows that the OE approach can be used to compute the maximum day-ahead flexibility per LV end-user that can be unlocked while ensuring the safety of LV distribution networks. Unlike traditional methods, it models **three-phase unbalanced networks**—a critical step since DSOs often lack visibility on phase connections, which can be uneven and unpredictable. This method allows for a good trade-off between the accuracy of LV network representation and the computational complexity. This method can be directly applied to dynamic non-firm connection agreements, a rule-based flexibility mechanism, where end users are given dynamic limits depending on the network states.

Contribution to ALEXANDER objectives and impact

- New operational model for future proof active system management – allowing cost-efficient flexibility procurement and activation in a grid way. An accurate tool to compute dynamic operating envelopes of LV assets for flexibility provision
- Security of supply and balancing – Allowing LV flexibility to be safely aggregated and consequently, to participate in balancing services.
- Climate & energy transition – The tool supports the integration of distributed and renewable energy technologies into the overall electrical systems.
- Economic welfare – The economic welfare of the overall system improves when the maximum potential of LV flexibility can be unlocked safely.

How can DSOs benefit?

- The tool can be used to determine dynamic grid-safe limits of LV end-users, e.g., to support the implementation of NFCA without unnecessarily blocking flexibility.

How can consumers benefit?

- Residential consumers with flexible devices and non-firm connection agreements can safely participate in demand response or flexibility provision mechanisms, earning revenue by reducing or shifting energy use during high-demand periods.

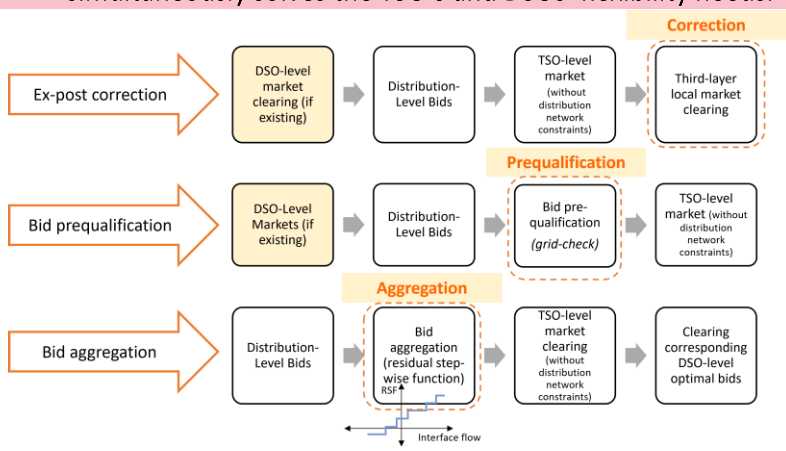
3.5.11 KER 11: Grid-impact aware bid forwarding methods/tools

Problem

Local flexibility markets are emerging in Belgium, enabling DSOs to manage congestion while FSPs seek to also join TSO balancing markets. This creates a coordination challenge: flexibility bids must be forwarded between markets, but what is safe for one grid operator may create problems for another. Without proper alignment, risks include unsafe dispatch, double activations, or blocked bids, undermining market trust and efficiency. To unlock the full value of distributed flexibility, it is crucial to guarantee that bids participating in multiple markets can be safely activated while ensuring both distribution and transmission grid security.

ALEXANDER solution: Three grid-impact aware bid forwarding methods are developed: an ex-post corrective market mechanism, bid prequalification, and bid aggregation.

- Ex-post corrective market: an additional layer of local market after DSO-TSO sequential market to resolve any grid issues caused by the TSO-level market clearing distributed flexibility resources.
- Bid prequalification: Prequalifying bids that will be forwarded to the TSO-level market based on the current state of the distribution grids.
- Bid aggregation: Aggregating distribution-level bids such that only grid-safe aggregated bids are forwarded to the TSO-level market. Therefore, clearing this market simultaneously solves the TSO's and DSOs' flexibility needs.



Contribution to ALEXANDER objectives

- Novel methods that support market-based flexibility provision mechanisms.
- Security of supply and balancing - The results improve the market-based flexibility provision process, specifically in forwarding bids from local markets to a system-wide market.
- Climate & energy transition - Allowing renewable energy sources in distribution grids to participate not only in local flexibility markets but also in a balancing market.
- Economic welfare - Bid forwarding is important in realizing the sequential market scheme, which is more economically efficient than disjoint/separate markets.

How can DSOs benefit?

Grid safety - Activation of distribution-level flexibility is safe for the local grid. DSOs can utilize the ex-post corrective market and bid prequalification as ex-post and ex-ante mechanisms to achieve this.

How can TSO benefit?

Improved market efficiency - The flexibility procurement cost can be reduced when distributed flexibility is allowed to participate in local and system-wide markets, as long as clearing such resources does not cause additional network issues.

How can FSPs benefit?

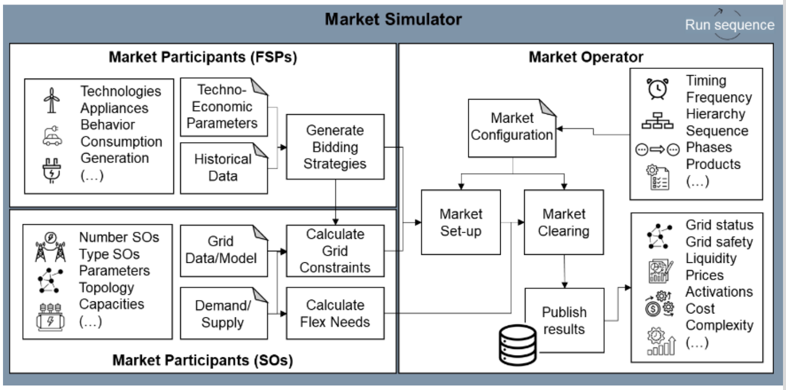
Value stacking - Distributed flexibility can participate in local and system-wide markets, increasing the chance of the flexibility being cleared and the FSPs being remunerated.

3.5.12 KER 12: Simulation environment for the comparison between different TSO-DSO coordinated flexibility market models

Problem

In Belgium, DSOs are beginning to establish local flexibility markets to manage congestion, while Elia already operates national balancing markets. These markets often involve the same participants but pursue different objectives, creating potential conflicts if actions are not aligned. For example, an activation that supports system-wide balancing may worsen a local congestion issue, or vice versa. To avoid inefficiencies, unsafe dispatch, or lost flexibility potential, effective coordination between markets is essential. Since coordination can be designed in multiple ways, it becomes crucial to objectively evaluate and compare different coordination schemes.

ALEXANDER solution: The ALEXANDER simulation environment for TSO-DSO coordinated markets can simulate local flexibility markets, balancing markets, and TSO-DSO coordinated markets. It can run with real network and bid data as well as various market configurations, including those with grid-impact aware bid forwarding mechanisms. It produces market-clearing results, clearing prices, flexibility activation, and grid status, allowing for extensive analysis of the market outcomes.



Contribution to ALEXANDER objectives

- Comprehensive simulation environment for coordinated flexibility markets.
- Security of supply and balancing - It provides an integrated view of market processes and market results when different markets (local and balancing markets) are run under various configurations. Therefore, it helps system operators and regulators in formulating policy recommendations and future development of flexibility markets in Belgium.
- Climate & energy transition – Inclusion of local flexibility market model allows assessment of participation of renewable and sustainable resources.
- Economic welfare – Economic assessment of various coordinated market designs can be made.

How can TSO and DSOs benefit?

System operators can simulate various coordinated market schemes to obtain quantitative evidence of their performance. The tool can readily take real network data from the SOs and has several network model options that the SOs can choose from.

Such objective and detailed assessments can support the discussion among SOs in setting up their market-based flexibility provision mechanisms.

How can regulators and policy makers benefit?

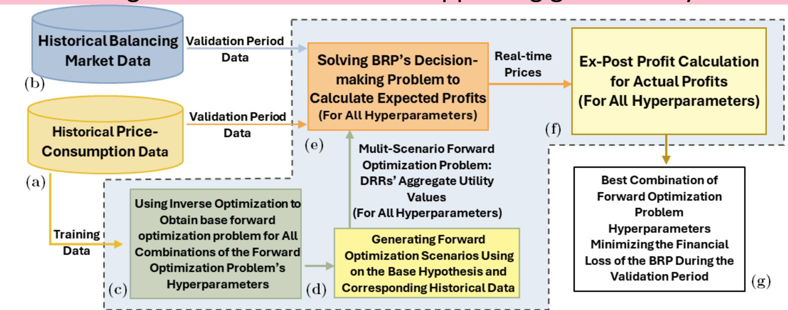
Objective comparison between different coordination options helps policy makers to ensure regulatory provisions or obligations are set in a proper way, not to block future evolutions in market design.

3.5.13 KER 13: Price-Based Demand Response Participation in Balancing Services: A Value-Oriented Multi-Scenario Inverse Optimization Framework

Problem

To integrate growing shares of renewables, power systems increasingly rely on demand response (DR) to shift or reduce consumption when needed. Price signals, such as real-time pricing (RTP), are a key tool to activate this flexibility, steering households and small devices to adapt their usage in line with system needs. Yet, under RTP, consumer reactions to price signals are uncertain and inconsistent. This unpredictability exposes aggregators to financial risks: overestimating flexibility may cause penalties for non-delivery, while underestimating it leads to missed revenues and higher system costs. Without accounting for behavioural uncertainty, RTP-based demand response may undermine both grid reliability and the economic viability of flexibility markets.

ALEXANDER solution: a data-driven framework that models uncertainty in consumer price-response under real-time pricing (RTP). It estimates how a pool of demand response resources (DRRs) collectively reacts to price signals by learning from past data. This estimation explicitly incorporates DRRs uncertainty and its impact on aggregators' decisions. The framework then integrates these uncertainty-aware parameters into the decision-making problem of a BRP participating in the single-price imbalance market, where the method maximizes expected revenues while accounting for financial risks from over- or under-activation. By doing so, it enables more reliable activation of residential flexibility, protects aggregators from financial losses, and strengthens the role of DR in supporting grid stability.



Contribution to ALEXANDER objectives

- Flexibility provision – enables large-scale activation of residential flexibility through real-time pricing while minimizing financial risks from consumer uncertainty
- System operations and economics – improve BRP efficiency, reduce reliance on fossil-based balancing, lower system costs, and boost aggregator confidence in indirect demand response
- Consumer participation and market accessibility – lowers barriers for small consumers by avoiding direct control, reducing their risk and enabling broader, more inclusive participation in flexibility markets
- Environment – supports higher renewable integration, lower CO_2 Emissions, and helps decarbonize balancing services

How can aggregators (e.g., BRPs) benefit?

Gain more stable profits and reduced penalties by using uncertainty-aware price signals that align consumer flexibility with market needs.

Can coordinate large pools of small-scale loads more efficiently without needing detailed individual data, preserving privacy while ensuring market participation.

How can System Operators benefit?

Benefit from improved grid balancing through more predictable and effective demand-side flexibility frameworks that mobilize large numbers of behind-the-meter consumers.

How can Policy Makers benefit?

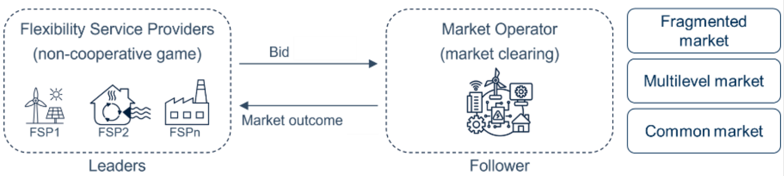
Support scalable, privacy-preserving flexibility solutions that reduce system costs and help meet decarbonization targets through residential demand response.

3.5.14 KER 14: Simulation environment for analysing the likelihood and impact of FSP strategic bidding in TSO-DSO coordinated flexibility markets

Problem

The emergence of local flexibility markets introduces new TSO-DSO coordination schemes but also the risk of strategic bidding by flexibility service providers (FSPs). Instead of bidding their true costs or available capacities, FSPs may inflate prices, understate capacity, or shift bids to the market where they expect higher profits. Such behaviour can raise overall procurement costs, reduce efficiency, and distort dispatch by sidelining cheaper or more grid-relevant resources. In coordinated markets, it may also worsen conflicts between TSO and DSO needs, as bids valuable locally could be withheld for system-level services. Since local flexibility markets are still immature with few players, they are especially vulnerable to market power, making the analysis of strategic bidding impacts essential.

ALEXANDER solution: The ALEXANDER simulation environment for FSP strategic bidding in TSO-DSO coordinated markets models the interaction between FSPs and the market using Stackelberg game theory. In this model, the FSPs are considered as a group of leaders playing a non-cooperative game to maximize their revenue from the market, while the market operator is a follower that clears the market based on the bids provided by the FSPs. By using this advanced model, the impact of bidding behaviour on the market can be shown. Additionally, FSPs are assumed to have bounded rationality and strategically bid using some knowledge of the others' bids. The coordinated market models used are based on KER 12.



Contribution to ALEXANDER objectives

- An advanced model to simulate strategic bidding of FSPs in coordinated flexibility markets, allowing for in-depth analysis of the bidding behaviour of FSPs.
- <u>Security of supply and balancing</u> – Understanding how market players behave in market-based flexibility provision is important to safeguard this mechanism and provide recommendations when other mechanisms, such as implicit ones, are needed.
- <u>Economic welfare</u> - The efficiency of market mechanisms for balancing, as well as for local flexibility provision, is impacted by the bidding behaviour of market participants. Understanding these impacts is important to ensure efficient market results.

How can DSOs and TSO benefit?

System operators can understand some strategic bidding behaviour that FSPs may perform, its potential impact, and ultimately develop solutions to mitigate the behaviour and/or reduce the impact. Subsequently, appropriate mitigation and/or prevention actions can be formulated.

How can regulators and policy makers benefit?

Strategic behaviour and gaming are often claimed to be a danger for flexibility markets, i.e., as an argument to slow down the deployment of such markets. Policy makers and regulators need to be able to objectively analyse the impact of bidding behaviour to make informed decisions.

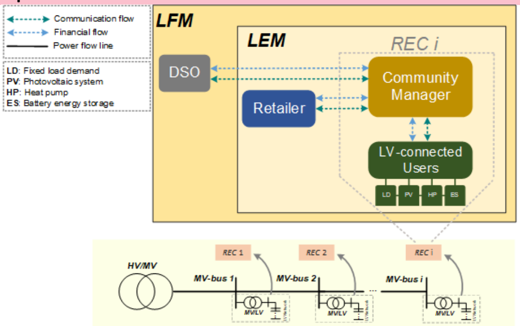
3.5.15 KER 15: A Mechanism for Heterogenous Energy Communities Providing Baseline Services in Local Flexibility Markets

Problem

Belgium's growing adoption of rooftop PV, EVs, and heat pumps is placing increasing stress on the LV grid, particularly during peak production or demand periods. Traditional grid reinforcement is costly and slow, making local flexibility, adjusting household energy consumption or production, a more efficient alternative. However, existing flexibility mechanisms are poorly suited to citizen-led energy communities, which are diverse in both technical capacity and user motivation. Current models often assume users are purely financially driven, overlooking real-world preferences such as comfort and environmental values. There is a need for a coordinated, transparent approach that enables households to trade energy locally, respects LV grid limits, and fairly distributes flexibility benefits, all while supporting DSO grid management and regulatory goals.

ALEXANDER solution: This result delivers a framework for energy communities to participate in local flexibility markets (LFMs) while respecting grid constraints and user diversity. Key features include:

- Dynamic Pricing: Stackelberg-based pricing tailored to user preferences and grid needs.
- User Modeling: Reflects financial, comfort, and environmental motives via weighted utilities.
- Baseline & Flexibility Tools: Manipulation-resistant baselines and grid-aware coordination with DSOs.
- Fair Benefit Sharing: Shapley-value method ensures equitable revenue distribution.



Contribution to ALEXANDER objectives and impact

Implications for Flexibility Provision (to DSO)

Climate objectives – this solution allows to reflect environmental motives of users, allowing to ensure such priorities can be given by users

Economic welfare – by accounting for personal goals, consumer welfare increases as such intrinsic values can be accounted for.

Security of supply and grid services – this approach further takes away barriers that originally blocked households to trade energy locally, while still respecting LV grid limits, and fairly distributes flexibility benefits, all while supporting DSO grid management and regulatory goals.

How can DSOs benefit?

Providing a mechanism to tap into the flexibility of energy communities in a way that is technically robust, economically fair, and resistant to manipulation.

How can Community Members benefit?

Participate fairly in flexibility markets while aligning with personal goals—financial, comfort, or environmental.

How can Aggregators benefit?

Coordinate household assets more effectively with trusted pricing and reliable baselines.

How can Local Coordinators benefit?

Manage community energy flows and grid interactions while ensuring fairness and compliance.

3.5.16 KER 16: Energy system planning with consumer preference for low voltage flexibility in the context of Belgium

Problem

As Belgium integrates more renewable energy sources, ensuring system adequacy (i.e., having enough generation and flexibility to meet demand at all times) becomes increasingly challenging. Conventional power plants are running less frequently and becoming less profitable, while the rise in electric vehicle (EV) adoption adds both stress and potential flexibility to the grid. Fully uncoordinated EV charging can drive up infrastructure costs, but flexible charging could help balance renewable variability. Unlocking this flexibility, however, is not only a technical issue, it also depends on the willingness of consumers to participate. Without properly accounting for diverse consumer preferences, flexibility potential could be misjudged, leading to either underinvestment in reliability or unnecessary system costs.

ALEXANDER solution: To address consumer preference in energy system planning models we propose the combination of DCEs and energy system planning models (ESPM).

In **existing** models, the results of DCEs have a place in the scenario design and during a post analysis. In our study, we used the TIMES BE model for a scenario analysis following a selected set of the PATHS2050 scenarios (EnergyVille). In the post analysis we compared the remuneration budget (i.e. the difference between an energy system with and without flexible chargers) to the stated preference for remuneration when adopting flexible chargers. In general, the remuneration budgets are sufficient beyond 2030.

For **future** models, consumer preferences should be integrated directly in the design of the energy systems. In our study, we considered financial concerns and driving range anxiety. While, the implementation of the approach is challenging, the results provide a more realistic availability and use of flexible EV chargers. From the modelling exercise in a limited setup, we see that available flexibility is more limited and more expensive. Yet, the system remains incentivised to promote the adoption of flexible EV chargers.

How can TSOs benefit?

Surveys as part of adequacy studies to gain insight in the gap between scenarios on flexible chargers and actual available flexibility.

How can regulators and policy makers benefit?

Insights in the remuneration budget for the adoption of flexible chargers helps with policy design.

Contribution to ALEXANDER objectives

- Integrated framework for Belgium for considering consumer preference in existing energy system planning models, which is increasingly important for more flexible energy systems.
- Insights in the remuneration budget for adoption of flexible chargers.

3.5.17 KER 17: Bounded rationality of energy sharing using solar-battery systems

Problem

Accurately estimating the flexibility potential of residential solar-battery systems is challenging due to the complex and diverse decision-making behaviours of households. Conventional models often assume fully rational or uniform participation, overlooking how individuals perceive risk, value future savings, and respond to control over their energy use. These behavioural shortcuts and variations can significantly distort forecasts and lead to poorly targeted flexibility programs. Without a clear understanding of how preferences, trust, and control dynamics influence willingness to participate, system operators and policymakers risk overestimating available flexibility and designing incentives that fail to engage the intended users.

ALEXANDER solution:

To address these behavioural uncertainties, ALEXANDER used **Discrete Choice Experiments (DCEs)** grounded in **Cumulative Prospect Theory** to quantify how households value, perceive, and respond to energy-sharing options from solar-battery systems. The analysis identified two key segments: one willing to sell excess energy and one preferring to retain it.

Preferences varied with **framing**, **trust**, and **who controls dispatch**—most respondents preferred delegating to their energy retailer or system operator over private firms. These insights provide a realistic estimate of household participation and inform consumer-centric tariff and program design, offering a more accurate upper bound on the dispatchable flexibility from residential batteries.

	Energy selling agreement 1	Energy selling agreement 2	No selling agreement
Solar-battery **manager** (The manager controls the sale of your electricity, determining when and how much is sold.)	**Yourself** (Using your smartphone)	**Private firm** (Energy aggregator)	**€ 300** annual net reward (**100%** probability) Your household will use all of the solar-battery's energy without selling any back to the grid.
Your total net annual **reward** (probability)	**€ 330** (**90%** probability) **€ 30** (**10%** probability)	**€ 450** (**50%** probability) **€ 150** (**50%** probability)	
	○	○	○

Contribution to ALEXANDER objectives and impact

- Advance Pillar 1's consumer view. We measure how households evaluate money, risk, and control using DCEs with prospect-theory, capturing bounded rationality in LV user decisions.
- We implement the DCE approach to consumer preferences (Obj. 2) by running a prospect-theory DCE on energy selling and who manages the battery; and we provide simple, two-segment evidence (energy-selling vs. non-selling) with parameter estimates that improve representation of heterogeneous, bounded-rational LV flexibility (Obj. 4).
- Actionable, consumer-centric design inputs. Results show who people prefer to sell through (retailer/system operator over a private firm) and how framing affects choices—directly serving Pillar 1's focus on consumer-centric products and perceived value

How can DSOs and retailers benefit?

Around half of households are willing to delegate control and sell energy from their solar-battery systems. This willingness strongly depends on trust, with respondents showing clear preference for energy retailers or system operators over private companies.

For DSOs and retailers, this means focusing on trusted, transparent partnerships to engage the receptive half, while trust-building measures will be essential to reach the more hesitant segment and unlock broader flexibility potential.

3.5.18 KER 18: Methods for grid-safe local energy exchange (peer-to-peer trading)

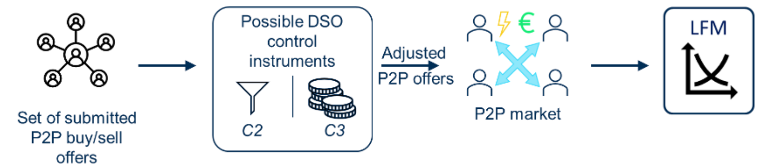
Problem

Local energy exchange and peer-to-peer (P2P) trading is gaining increased importance for empowering end-consumers and supporting their investments in renewable generation and storage. However, P2P trading implies an increase in injection and offtake of end-users at different parts of the grid, leading to changes in power flows, grid status, and the DSO's flexibility needs. Hence, quantifying the impacts of P2P trading on the distribution grid and identifying mechanisms that DSOs can implement to ensure that such P2P trading can be carried out in a grid-safe manner is essential for empowering local energy exchange while concurrently safeguarding the grid.

ALEXANDER solution: ALEXANDER has developed a method to a priori quantify (using closed-form expression) the impacts of each possible P2P trade on the distribution grid operation and on the grid's flexibility needs, where the economic impact of the latter is quantified via the modification to the DSO costs as part of a local flexibility market (LFM). The ALEXANDER project has then proposed two DSO control instruments, which can be applied when the grid is under stressed conditions, and through which the DSO can enable P2P trading while safeguarding the grid:

- **Preventive blocking method** (C2): The DSO preventively blocks P2P trades that are deemed harmful to the grid.
- **Corrective incentive/disincentive mechanism** (C3): The DSO provides price incentives (via cost-adjustment factors leading to subsidies or penalties) to encourage trades that are helpful to the grid and discourage harmful trades.

The project then introduced a structured method for comparing (i) the effectiveness (grid safety, impact on congestions), (ii) efficiency (impact on flexibility needs and their procurement costs, level of limitation on P2P trading and P2P market efficiency), and (iii) practicality (complexity, coherence with regulatory frameworks) of the proposed methods based on the local context in comparison to the non-controlled P2P trading option (C1).



Contribution to ALEXANDER objectives

- Operational models for future-proof active system management: Novel set of DSO control instruments to safeguard grid operation while enabling P2P trading.
- Security of supply and balancing: operational methods for ensuring safe grid operation.
- Climate & energy transition: Empowering end-user investment in renewable generation and storage.

How can DSOs benefit?

Enhancing the DSO's visibility of the impact of P2P trading on the grid, and deploying control instruments to mitigate potential negative impacts, harness positive effects, and facilitate local energy exchange.

How can consumers benefit?

Restrictions on P2P trading are minimized and based on transparent methods, thereby supporting the economic and sustainability benefits of local energy exchange.

How can policy makers benefit?

A transparent set of control instruments providing the basis for grid-safe local energy exchange, thus benefiting consumers and energy communities while preventing potential harmful impacts to the local grids when in stressed conditions.

This project has received funding from Energy Transition Fund 2021 FPS Economy, SMEs, Self-employed and Energy.