InStaFlex - D2.3 Report summarizing non-technical and non economic barriers

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Instaflex Project – Results Report

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3. Executive summary

This deliverable presents a comprehensive analysis of non-technical and non-economic barriers that significantly affect the adoption and valorisation of flexible industrial and commercial assets in modern energy systems. While previous deliverables in this research series, specifically D2.1 and D2.2, have successfully quantified the technical constraints and activation costs associated with flexibility provision, this report deliberately shifts focus to examine the equally critical human, organizational, regulatory, and operational factors that can substantially hinder or even prevent flexibility provision to electricity markets.

The investigation has revealed several key barrier categories that consistently emerge across different industrial sectors and operational contexts. User perception and acceptance of automated control systems or load adjustments represents a fundamental challenge, as operators often harbor concerns about relinquishing direct control over their processes. Behavioral uncertainty introduces another layer of complexity, manifesting through inconsistent participation patterns or unexpected deviations from planned operational schedules. Planning and integration challenges arise when attempting to incorporate flexibility mechanisms within existing operational processes that were designed without flexibility considerations. Operational and environmental safety constraints frequently limit the extent to which flexibility can be exploited, as industrial facilities must prioritize safety compliance and environmental standards. Finally, regulatory, legal, and market limitations, encompassing elements such as grid codes, tariff structures, and licensing requirements, create structural barriers that affect participation feasibility.

Beyond identifying these barriers, this report also documents and analyzes good practice solutions that have been successfully implemented in various industrial contexts to overcome or mitigate these challenges. These solutions provide valuable insights for future flexibility deployment initiatives and demonstrate that non-technical barriers, while significant, can be systematically addressed through appropriate strategies.

4. Introduction

Flexible demand and storage resources represent a crucial component of modern electricity systems, offering significant potential for grid balancing operations and renewable energy integration. As electricity grids worldwide transition toward higher shares of variable renewable generation, the ability to modulate demand and storage charging patterns becomes increasingly valuable for maintaining system stability and reducing the need for conventional backup generation capacity.

However, the pathway from technical potential to actual deployment of flexibility resources is rarely straightforward. Beyond the technical capabilities of equipment and the economic viability of participation, non-technical barriers frequently emerge as the determining factors in whether flexibility can be effectively deployed in real-world industrial and commercial settings. These barriers operate at multiple levels, affecting individual operators' willingness to participate, organizations' ability to integrate flexibility into their operations, and the broader regulatory environment that governs market participation.

This report undertakes a systematic assessment of these non-technical barriers, drawing on multiple complementary sources of information and analysis. The research foundation combines an extensive literature review [see list below] of industrial case studies and energy system research and structured interviews with practitioners who have direct experience with flexibility implementation. This multi-faceted approach ensures that the identified barriers reflect both theoretical understanding and practical realities encountered in actual deployment scenarios.

The objective is to provide stakeholders across the flexibility value chain with a comprehensive understanding of the non-technical challenges they may encounter and the proven strategies available to address them. This includes industrial facility managers considering flexibility participation, energy service companies designing flexibility programs, policymakers developing supportive regulatory frameworks, and researchers seeking to advance the state of knowledge in this rapidly evolving field.

5. Methodology

As indicated above, the assessment methodology employed in this research combines qualitative and semi-quantitative analysis approaches to ensure comprehensive coverage of the barrier landscape while maintaining analytical rigor. This mixed-method approach recognizes that non-technical barriers often resist pure quantification but can nonetheless be systematically characterized and compared. In particular, as set forward, we combined literature review with structured interviews.

6. Key barrier categories

6.1 User perception and incentives

One of the most fundamental barriers to flexibility adoption emerges from the perceptions and motivations of the industrial and commercial operators who must ultimately authorize and sustain flexibility provision. These operators, ranging from facility managers to production supervisors to maintenance personnel, often exhibit hesitancy toward allowing automated control systems to modulate their processes.

It appears to us that users frequently overestimate the risks associated with flexibility provision. A production manager may envision worst-case scenarios where automated load curtailment disrupts a critical manufacturing process, even when the proposed flexibility operates well within safe operational boundaries. Similarly, building managers may resist HVAC flexibility due to concerns about occupant complaints, despite evidence that properly designed flexibility causes minimal comfort impact. This risk perception gap between actual and perceived consequences creates a significant barrier that purely technical or economic arguments often fail to overcome.

The incentive structure surrounding flexibility participation further complicates adoption decisions. In many cases, the individuals responsible for operational decisions do not directly benefit from flexibility revenues. A facility manager whose performance is evaluated primarily on production metrics or uptime may view flexibility as introducing risk without corresponding reward. Even when financial benefits accrue to the organization, the absence of recognition incentives for the individuals managing flexibility implementation reduces their motivation to champion these initiatives.

Mitigation strategies that have proven effective in addressing perception and incentive barriers typically operate on multiple levels. Transparent dashboard systems that provide real-time visibility into flexibility operations, their impacts, and resulting financial benefits help build confidence and demonstrate that concerns about disruption are largely unfounded. These systems allow operators to observe flexibility provision occurring without catastrophic consequences, gradually shifting risk perceptions toward more realistic assessments.

Small-scale pilot implementations serve a similar confidence-building function. Rather than attempting full-scale flexibility deployment from the outset, successful programs often begin with limited trials that demonstrate reliability and minimal operational impact. These pilots allow operators to develop familiarity with flexibility concepts in a low-stakes environment before committing to broader participation.

Addressing the incentive gap requires more creative approaches that recognize the human factors at play. Some organizations have successfully employed gamification strategies, creating friendly competition among facilities or teams to achieve flexibility targets.

6.2 Behavioral uncertainty

Even when operators accept flexibility participation in principle, human behavior introduces variability that can significantly compromise the reliability and predictability of flexibility scheduling. This behavioral uncertainty manifests in various forms across different operational contexts, but consistently represents a challenge for flexibility aggregators and system operators who rely on accurate forecasts of available flexibility.

Manual overrides of automated setpoints represent one of the most common manifestations of behavioral uncertainty. An operator may observe a temperature, pressure, or other parameter approaching the edge of its normal operating range and manually adjust the setpoint, overriding the flexibility control system. While such interventions often reflect well-intentioned efforts to maintain safe operations, they can unexpectedly reduce or eliminate flexibility provision at critical moments. The frequency and predictability of these overrides vary substantially across facilities and individuals, creating uncertainty that is difficult to model or anticipate.

Variable adherence to planned load curtailments presents similar challenges in contexts where flexibility relies partially on manual actions. A planned reduction in non-essential loads may be fully implemented on one occasion but partially skipped on another, depending on the operator's judgment about current conditions and priorities. This variability may reflect legitimate operational considerations, but it nonetheless reduces the reliability of flexibility commitments.

The root causes of behavioral uncertainty are complex and multifaceted. In some cases, operators lack complete understanding of flexibility requirements or the importance of adhering to scheduled actions. Competing priorities and time pressures can lead to flexibility commitments being deprioritized when immediate operational issues demand attention. Organizational culture and leadership support also influence whether flexibility participation is treated as a core responsibility or as an optional activity that can be abandoned when convenient.

Mitigation strategies for behavioral uncertainty generally aim to either reduce the human role in moment-to-moment flexibility provision or improve the reliability of human behavior when involvement is necessary. Incentive-based contracts with clear performance metrics create accountability for behavioral reliability while providing motivation for consistent participation. When flexibility payments depend on demonstrated reliability over time, with penalties for unexplained deviations, operators have stronger reasons to maintain consistent behavior patterns.

Hybrid automation-human control schemes represent another effective approach. These systems handle routine flexibility provision automatically while providing clear interfaces for necessary human intervention in truly exceptional circumstances. By designing systems that minimize the need for manual decision-making during normal operations, these approaches reduce opportunities for behavioral variability while still allowing human override when genuinely warranted.

Training and awareness programs can substantially improve behavioral reliability when properly designed and implemented. Effective programs go beyond simple instruction to build genuine understanding of why flexibility matters, how the control systems function, and what operational margins exist to provide flexibility safely. When operators understand that flexibility operations include substantial safety margins and that their adherence to schedules contributes to grid reliability and organizational revenue, behavioral consistency typically improves.

6.3 Planning and integration challenges

Integrating flexibility provision into existing industrial processes presents substantial planning and coordination challenges that extend well beyond the technical capabilities of individual assets. Industrial facilities operate as complex, interconnected systems where modifications to one process can have cascading effects on others. Introducing flexibility into this environment requires careful consideration of production schedules, maintenance activities, raw material availability, and numerous other operational constraints.

Heat and cooling loads in industrial settings illustrate these integration complexities particularly well. Many industrial processes require heating or cooling at specific times coordinated with production activities. A food processing facility may need cooling capacity precisely when products move from cooking to packaging stages, regardless of whether that timing coincides with favorable electricity prices or grid needs. Similarly, an e-boiler providing steam for industrial processes must generate heat in alignment with production schedules that were established based on factors having nothing to do with electricity system flexibility.

Water treatment cycles present comparable integration challenges in facilities where water quality requirements drive operational timing. Treatment processes often follow prescribed sequences with specific duration requirements to ensure regulatory compliance and product quality. While some temporal flexibility may exist in when these cycles begin, downstream operations that depend on treated water availability constrain the degree of schedule modification that remains feasible.

The challenge extends beyond individual process constraints to encompass enterprise-level coordination requirements. Production planning systems, maintenance scheduling tools, inventory management processes, and quality control procedures all interact with flexibility potential. Introducing flexibility provision requires these various systems and processes to communicate and coordinate in ways that may not have been necessary previously. Information technology infrastructure that was never designed to support flexibility decision-making may struggle to provide the data flows and integration points that effective flexibility management requires.

Organizational silos compound these technical integration challenges. Energy management decisions may be made by facilities teams with limited visibility into production planning, while production schedulers may have little awareness of energy costs or flexibility opportunities. Maintenance planning may occur on separate timelines without consideration of flexibility implications. Breaking down these silos to enable coordinated flexibility provision requires organizational changes that can prove challenging to implement.

Mitigation strategies for planning and integration challenges typically combine technical tools with organizational process improvements. Flexibility planning tools that integrate with enterprise resource planning (ERP) systems or supervisory control and data acquisition (SCADA) platforms provide the data visibility and coordination capabilities necessary for effective flexibility management. These tools can automatically identify feasible flexibility windows by analyzing production schedules, maintenance calendars, and operational constraints, reducing the manual coordination burden.

Simulation-based scheduling approaches allow facilities to explore flexibility scenarios before committing to specific operational changes. By modeling different flexibility provision patterns and their impacts on production, quality, and other operational objectives, these simulations help identify optimal flexibility windows that maximize energy value while minimizing operational disruption. The ability to test approaches virtually before implementing them physically reduces risk and builds confidence in flexibility strategies.

Aggregation of multiple assets within a facility or across a portfolio of facilities provides another powerful mitigation approach. When flexibility draws on numerous assets rather than relying on any single process, individual constraints become less binding. If one asset temporarily cannot provide flexibility due to production requirements, other assets can potentially compensate. This portfolio effect smooths individual process constraints and improves overall flexibility reliability.

6.4 Operational and environmental safety

Safety regulations and environmental compliance requirements impose constraints on industrial operations that can significantly limit flexibility deployment potential. These constraints emerge from multiple sources, including occupational safety regulations designed to protect workers, environmental permits that limit emissions or discharges, and internal corporate safety standards that may exceed regulatory minimums. While these requirements serve essential protective functions, they can create rigid operational boundaries that reduce flexibility potential.

Temperature constraints illustrate how safety requirements impact flexibility in thermal systems. An industrial e-boiler may theoretically be capable of varying its steam production across a wide range to provide flexibility, but maximum allowable temperature deviations may be tightly constrained by safety considerations related to equipment integrity, product quality, or worker safety. Exceeding these temperature limits, even briefly, could trigger automatic shutdowns, damage equipment, compromise product quality, or create hazardous conditions. These safety thresholds effectively define inflexible boundaries within which any flexibility must operate.

Water treatment facilities face particularly stringent environmental constraints that limit operational flexibility. Regulatory limits on water quality parameters mean that treatment processes must reliably achieve specific outcomes regardless of electricity prices or grid needs. Effluent discharge timing may be constrained by environmental permits that specify when and how treated water can be released. While some flexibility may exist in the timing of treatment cycles, the requirement to meet quality standards and discharge limitations creates inflexible boundaries that cannot be compromised for flexibility provision.

The interaction between safety requirements and flexibility potential creates a fundamental tension. Safety standards appropriately prioritize protection of people and environment over economic optimization or grid support objectives. Facilities and operators understandably exhibit strong risk aversion when safety considerations are involved. Even when technical analysis suggests flexibility can be provided safely within appropriate margins, the consequences of miscalculation or unexpected events can be severe enough to discourage participation.

Liability concerns amplify this conservative approach to safety-bounded flexibility. If flexibility provision contributes to a safety incident, even indirectly, the facility owner and operators may face legal liability, regulatory sanctions, and reputational damage far exceeding any financial benefits from flexibility participation. This asymmetric risk profile, where downside consequences substantially exceed upside benefits, naturally drives conservative decision-making that limits flexibility deployment.

Mitigation strategies addressing safety and environmental constraints must fundamentally respect these boundaries rather than attempting to eliminate them. Conservative flexibility envelopes that maintain substantial safety margins represent the primary approach. Rather than operating at the edge of safe conditions to maximize flexibility value, successful programs typically define flexibility ranges that remain comfortably within established safety thresholds. This approach may reduce theoretical flexibility potential but substantially improves reliability and reduces risk.

Continuous monitoring systems with automated alarms provide essential safeguards when providing flexibility near safety boundaries. These systems track relevant parameters in real-time and trigger automatic responses when values approach concerning levels. Alarms can notify operators of developing issues, while automatic curtailment mechanisms can cease flexibility provision and return systems to safe baseline conditions without requiring human intervention. The existence of these protective layers helps overcome risk aversion by demonstrating that multiple safeguards prevent safety boundary violations.

Certification and validation of control algorithms by appropriate authorities can help address regulatory and liability concerns. When control systems undergo formal safety assessment and receive regulatory approval or certification from recognized bodies, facilities gain confidence that flexibility provision complies with safety requirements. This external validation provides both technical assurance and legal protection, as operators can demonstrate they employed appropriately certified systems rather than improvised approaches.

6.5 Regulatory and Market Constraints

The regulatory and market environment within which industrial flexibility operates can either enable or severely constrain participation feasibility. These structural factors often prove particularly challenging to address because they lie largely outside individual facilities' control and require collective action or policy changes to resolve. Nevertheless, they represent critical barriers that determine whether technically feasible and economically attractive flexibility can actually be deployed.

Market access limitations present a fundamental barrier for many potential flexibility providers, particularly smaller industrial and commercial entities. Ancillary service markets in many jurisdictions establish minimum participation thresholds designed around large conventional generation units. An industrial facility with several megawatts of flexible load may find itself unable to participate directly in markets requiring tens of megawatts minimum bid sizes. Even when aggregation theoretically addresses this challenge, regulatory frameworks may not clearly permit aggregated participation or may impose requirements that make aggregation economically unattractive.

Tariff and contract structures frequently fail to align with flexible operation patterns, creating economic barriers to participation. Industrial electricity tariffs typically were designed assuming relatively constant consumption patterns, with structures optimized for that operating mode. When facilities attempt to provide flexibility by varying consumption in response to grid needs, existing tariff structures may inadvertently penalize this behavior through demand charges, capacity charges, or other mechanisms that were never designed with flexibility in mind. The result can be situations where flexibility has positive value to the grid but creates net economic costs for the facility when tariff impacts are considered.

Grid code requirements and interconnection standards add another layer of regulatory complexity. These technical standards typically specify how generation and demand resources should behave and what capabilities they must possess to connect to the grid. However, many grid codes were written when demand response and distributed flexibility were uncommon, resulting in requirements that may be inappropriate or overly burdensome for flexible loads. The lack of clear guidance specifically addressing aggregated industrial flexibility creates regulatory uncertainty that discourages participation.

Licensing and market participant registration requirements can impose administrative burdens that deter smaller players. Becoming an authorized market participant may require extensive documentation, financial guarantees, or ongoing reporting obligations that small and medium enterprises find difficult to justify relative to their potential flexibility revenues. While these requirements serve legitimate purposes related to market integrity and reliability, they can create barriers to entry that effectively exclude entire categories of potential flexibility providers.

The lack of standardization across jurisdictions compounds these challenges for organizations operating in multiple regions. A company with facilities in several European countries may encounter substantially different market rules, technical requirements, and administrative processes in each location. This regulatory fragmentation prevents economies of scale in flexibility program development and requires separate, jurisdiction-specific approaches that increase costs and complexity.

Mitigation strategies for regulatory and market barriers typically require longer time horizons and more complex stakeholder coordination than solutions to technical or organizational challenges. Lobbying and policy engagement activities aim to modify regulatory frameworks to better accommodate flexibility provision. Industry associations, flexibility aggregators, and individual companies work with regulators and policymakers to identify regulatory barriers and propose solutions. While this process can be slow and outcomes uncertain, it represents the primary mechanism for addressing structural regulatory limitations.

The development and growth of flexibility aggregator businesses provides a market-based solution to several regulatory barriers. Aggregators specialize in navigating market participation requirements, accumulating sufficient volume to meet minimum bid sizes, and managing the administrative complexity of market participation. By serving as intermediaries between industrial facilities and electricity markets, aggregators allow smaller players to access flexibility opportunities they could not pursue independently. However, aggregation viability depends on regulatory frameworks that clearly permit this business model and allow aggregators to reasonably compensate participating facilities.

Dynamic tariff structures and innovative incentive mechanisms can help align economic signals with desired flexibility behaviors. Time-of-use tariffs, critical peak pricing, and real-time pricing approaches provide clearer price signals that reward flexible consumption patterns. Network tariffs that recognize and compensate the grid support value of flexible demand help overcome situations where flexibility benefits the system but penalizes individual consumers. However, implementing these tariff innovations requires regulatory approval and careful design to balance multiple objectives including revenue adequacy, equity, and simplicity.

Regulatory sandboxes and pilot program exemptions provide mechanisms for testing flexibility approaches within controlled environments before requiring full regulatory framework changes. These arrangements allow limited-scale flexibility trials to proceed under temporary waivers or modified requirements, generating evidence about what works and what regulatory modifications might be necessary for broader deployment. While not sustainable as permanent solutions, sandboxes and pilots can accelerate regulatory learning and build support for needed reforms.

7. Operational industrial solutions

Drawing on both published literature and the structured interviews conducted for this research, several operational strategies have emerged as particularly successful for leveraging industrial flexibility while addressing the barriers documented above. These solutions reflect accumulated practical experience from diverse contexts and provide proven pathways for facilities considering flexibility participation.

Automation and Control Systems

The foundation of successful industrial flexibility typically rests on sophisticated automation and control systems that manage the complexity of flexibility provision while minimizing manual intervention requirements. Predictive energy management systems (like we are building) represent the state of the art in this domain, employing forecasting algorithms to anticipate both facility energy needs and grid system conditions. These systems optimize flexibility provision decisions by considering multiple factors simultaneously, including electricity prices, grid signals, weather forecasts, production schedules, and equipment constraints. By automating these complex optimization calculations, predictive management systems enable flexibility provision at a scale and sophistication that would be impossible with manual approaches.

The design of automation systems must carefully balance autonomous operation with appropriate human oversight. Successful implementations typically feature automated schedule adherence as the default operating mode, with flexibility actions occurring automatically according to predetermined algorithms and schedules. However, these systems also provide manual override capabilities that allow operators to intervene when genuinely exceptional circumstances warrant human judgment. The key design challenge involves making overrides possible when needed while maintaining them as deliberate exceptions rather than routine occurrences. User interface design plays a critical role here, as systems that make overrides too easy invite behavioral unreliability, while systems that make overrides too difficult create frustration and potential safety concerns when rapid human intervention is genuinely necessary.

Asset Aggregation and Virtual Power Plants

The aggregation of multiple distributed assets into portfolio-based flexibility offerings addresses several barriers simultaneously while creating new opportunities for market participation. By bundling numerous assets, whether within a single facility or across multiple sites, aggregation reduces the impact of individual asset variability and unavailability. When one asset cannot provide flexibility due to operational constraints, other assets in the portfolio can potentially compensate, maintaining overall portfolio reliability even when individual components exhibit variability.

Virtual power plant constructs formalize this aggregation approach through coordinated control platforms that manage portfolios of distributed energy resources. These platforms combine flexible loads, distributed generation, and energy storage into virtual assets that can participate in electricity markets similarly to conventional power plants. The aggregation layer handles market interaction complexity, including bidding, scheduling, settlement, and performance verification, relieving individual asset owners of these administrative burdens.

Aggregation also creates economies of scale in market participation and system management. The fixed costs of market participation, control system development, and ongoing program management can be spread across numerous assets, making flexibility economically viable for assets that would struggle with these costs individually. Aggregators develop specialized expertise in flexibility provision and market interaction that would be difficult for individual facilities to justify developing internally.

The success of aggregation approaches depends critically on establishing appropriate contractual and compensation frameworks. Participating facilities must receive fair compensation for their flexibility contributions while aggregators need sufficient revenue to sustain their operations and continue platform development. Various models have emerged, ranging from simple revenue-sharing arrangements to complex pay-for-performance structures that reward reliability and penalize unavailability. The optimal approach depends on asset characteristics, market structures, and participant preferences.

Flexible Contracts and Incentives

The design of contracts and incentive structures profoundly influences flexibility program success by shaping participant motivations and establishing clear expectations. Pay-for-performance models represent one particularly effective approach, tying compensation directly to demonstrated flexibility provision rather than capacity commitments or participation promises. Under these arrangements, facilities receive payment based on actual load modifications during grid need periods, with amounts determined by the magnitude and duration of their response. This direct linkage between action and compensation creates strong motivation for reliable participation while avoiding payments for unused or unreliable capacity.

Revenue-sharing arrangements provide alternative incentive structures particularly well-suited to aggregated flexibility programs. Rather than facilities receiving fixed payments for flexibility provision, revenue-sharing models distribute a portion of total program revenues back to participating facilities based on their contributions. This approach aligns participant and aggregator interests, as both benefit from maximizing program value through reliable flexibility provision and effective market participation. Revenue-sharing also provides automatic adjustment to changing market conditions without requiring contract renegotiation.

Monitoring and Visualization Tools

Transparency and visibility into flexibility operations play crucial roles in building trust, enabling performance verification, and supporting continuous improvement. Dashboard systems that present real-time and historical information about flexibility provision, impacts, and financial benefits serve multiple stakeholder needs simultaneously. For facility operators, these dashboards demonstrate that flexibility provision is occurring as intended without causing operational problems, gradually building confidence and reducing concerns about disruption. For management, dashboards quantify financial returns and system impacts, justifying continued participation and informing decisions about expanding flexibility commitments.

Effective dashboards typically present multiple layers of information accessible to different stakeholders. High level summaries provide executive perspectives on overall program performance, financial returns, and participation rates. More detailed operational views allow facility managers to understand precisely when and how flexibility was provided, what equipment was involved, and what operational parameters were affected. Historical trending capabilities enable identification of patterns and performance changes over time, supporting continuous improvement efforts.

The integration of monitoring and visualization systems with other enterprise systems enhances their value. When flexibility dashboards connect to production management systems, quality control platforms, and financial reporting tools, stakeholders can more easily understand relationships between flexibility provision and other operational objectives. This integrated perspective helps address concerns that flexibility might compromise other performance dimensions by demonstrating actual relationships rather than assumed tradeoffs.

8. Conclusions

This comprehensive assessment of non-technical barriers affecting industrial and commercial flexibility deployment reveals several clear conclusions that should inform future policy development, program design, and research priorities:

- User perception and behavioral uncertainty remain the largest barriers.
- Integration with existing industrial processes and safety requirements is key.
- Regulatory and market design improvements are necessary to incentivize small and medium industrial players.
- Aggregation, automation, and clear incentive structures are proven pathways to overcome barriers and maximize flexibility deployment.

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