D1.2 _Barriers and Solutions for Industrial Flexibility

GALILEO

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List of Acronyms and Abbreviations

aFRR	Automatic Frequency Restoration Reserve
AOD	ArgonOxygen Decarburization
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BRP	Balancing Responsible Party
CDS	Closed Distribution System
CfD	Contract for Difference
CIPU	Coordination of Injection of Production Units
CRM	Capacity Remuneration Mechanism
DC	Direct current
DR	Demand Response
DSO	Distribution System Operator
EAF	Electric Arc Furnace
EAN	European Article Number
EBO	Energy Policy Agreement
FCR	Frequency Containment Reserve
FSP	Flexibility Service Provider
HAZOP	Hazard and Operability (study)
IT	Information Technology
KPI	Key Performance Indicator
LDES	Long-Duration Energy Storage
mFRR	Manual Frequency Restoration Reserve
MVAr	Megavolt-ampere reactive (reactive power)
ORC	Organic rankine cylce
OT	Operation Technology
RE	Renewable Energy
RES	Renewable Energy Sources
SO	System Operator
SOP	Sulphate of Potash (potassium sulfate)
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
WIP	Work in progress

Executive Summary

This deliverable, developed within **GALILEO**, identifies the key barriers that limit industrial flexibility in Belgium and evaluates a structured set of solutions to overcome them. It combines a cross-sector view with sector-specific deep dives (chemicals, commercial data centres, food, iron & steel, non-ferrous). Beyond a theoretical inventory, the analysis is grounded in practical lessons from direct interactions with industrial partners.

The assessment draws on a literature scan and interviews/workshops with GALILEO partners. We (i) defined barriers across seven categories, (ii) questioned companies to score urgency and impact to prioritise the most material barriers (of which 57 barriers retained for further analysis), (iii) compiled suitable solutions for these filtered barriers, (iv) mapped solutions to barriers, and (v) assessed each solution against seven KPIs (i.e. electricity-market efficiency, grid operation, industrial competitiveness, effectiveness/scalability, proportionality, ease of implementation, and stakeholder acceptance) alongside a quantitative priority metric derived from industry input.

Three overarching conclusions emerge.

1. First, there is strong alignment between literature and practice on the centrality of technological and economic constraints, but company evidence brings additional emphasis to grid-related bottlenecks and regulatory ambiguity at the point of market access.
2. Second, sector context matters: similar barrier types manifest differently across processes and business models, which implies that one-size solutions will be inefficient.
3. Third, no single instrument unlocks flexibility on its own. Effective progress requires coordinated action across market design, roles and responsibilities, regulatory clarity, and company-internal readiness.

Why this assessment matters? Rising electrification and higher shares of variable renewables increase system variability and the value of demand-side response. Industry is often seen as a key contributor to flexibility provision, but the flexibility potential is heterogeneous and process constrained. Unlocking value therefore requires careful consideration of the constraints.

Barrier landscape. We organise barriers into seven categories—technological, economic, regulatory/legal, organisational, behavioural, informational, and competence-related. Across the more than eighty barriers identified, the most persistent themes are economic: firms face substantial upfront investment needs while prospective revenues from flexibility are uncertain, volatile, or perceived as risky. On the technological side, two issues repeatedly dominate. First, many processes operate within tight quality and safety envelopes, so even small deviations can jeopardise product specifications or service levels. Second, hard process limits—ramp-rate ceilings, start–stop penalties, and interdependencies between units—constrain what can be modulated in practice. These technical realities are often compounded by lagging digital prerequisites: fragmented metering, limited telemetry, and heterogeneous IT/OT standards make reliable activation and settlement harder than it should be. Beyond these, firms frequently point to the perceived inconvenience of organising demand response in day-to-day operations, limited familiarity with energy markets and products, and the high effort and uncertainty of project evaluation. Importantly, barriers rarely appear in isolation. Technical constraints inflate economic risk, regulatory ambiguity slows organisational buy-in, and information gaps magnify all three, creating reinforcing loops that raise the threshold for first participation.

Sectoral barrier insights. When companies score barriers by impact and urgency, three needs consistently appear in the high-priority, near-term quadrant. The first is reliable grid access: connection capacity is tight in many locations and there is widespread uncertainty about the terms and consequences of non-firm access. The second is safeguarding product or service quality when operating flexibly, which remains non-negotiable in process-sensitive environments. The third is revenue sufficiency and predictability, without clearer value signals and activation patterns, internal investment cases stall. Electro-intensive plants add a further near-term constraint: safe-ramp envelopes must be respected to avoid trips, wear, and non-delivery risk. Although these themes recur across sectors, their relative weight varies by context and technology.

Interviews sharpen and sometimes re-balance insights from the literature. Companies emphasise grid constraints more strongly than academic sources typically do, while confirming that economic and technical concerns are shared across sectors. The chemicals sector exhibits the broadest barrier spread; baseload process physics dominate, buffering and controls are often prerequisites, and protecting quality is central. Commercial data centres confront a firm IT load and therefore a narrow flexibility window confined to facilities (e.g., cooling); urban grid saturation and uncertainty around non-firm connections further limit options. In food, strong economic and notable organisational barriers stand out; campaign/seasonality and HACCP or product-quality requirements limit modulation, and energy-efficiency measures commonly outperform DR on net present value. Iron and steel balances technological, economic, and regulatory hurdles; batch metallurgy concentrates power demand into time-critical phases, where tight ramp limits and equipment-wear risks yield modest flexibility windows and weak business cases at current prices. Non-ferrous metals combine informational and organisational barriers with technical constraints: safe-ramp limits, equipment wear, the need for cooling/rectifier automation, process buffer vessels, and saturated grid access. Across sectors, when relevance and urgency are considered together, grid capacity and connection certainty, quality risk, and revenue uncertainty dominate near-term priorities.

Solution assessment. We assess solutions in clusters (i.e. market roles and responsibilities, market design, regulatory/legal, public support, infrastructure investments, company-internal levers, and information & awareness) and map each to the barriers it addresses. KPI results (market efficiency, grid operation, industrial competitiveness, effectiveness/scalability, proportionality, ease of implementation, and stakeholder acceptance) are read alongside an industry-derived priority score.

> **Market roles and responsibilities.** This is where companies most actively seek actionable change. Joint operation and pooling of demand response, together with operational guardrails, are rated high in urgency and impact. Pooling can be strongly enabling but is implementation-heavy: it needs clear governance, standardised contracts, and interoperable data exchange. Guardrails (opt-out clauses, activation caps, notice times) protect processes and budgets, yet if set too conservatively they reduce availability and degrade the technical suitability of the procured service. By contrast, risk-sharing templates between BRP, aggregator, and provider receive lower urgency ratings from firms but score very well across KPIs. They are proportionate—because they can be tailored to size and technology—and relatively straightforward to implement contractually, provided BRP acceptance is managed.
>
> **Market design.** Product design adaptations (e.g., ramp windows, activation duration and symmetry, baselines and settlement, risk-adjusted penalties) are a top company priority because they can admit processes that current products exclude. They deliver value when tightly linked to system use-cases, but they are slow to implement due to regulatory change and multi-stakeholder negotiation. Clear product definitions perform well across KPIs by reducing ambiguity on roles, telemetry, baselines, performance measurement and penalties, thereby lowering entry barriers and shortening onboarding. Standardisation and harmonisation are welcomed by firms yet difficult to deliver across actors and regions, and they tend to unlock less niche flexibility than expected. Enabling value stacking performs best in this cluster on effectiveness and efficiency—allowing assets to be used where they add most system value, increasing revenue potential, and strengthening investment incentives—but companies often rate

it only medium in priority because stacking introduces contractual and operational complexity (priority rules, anti-double-counting, and business-case tooling).

Regulatory/legal and public support. Regulatory and legal reforms are widely seen as necessary but not urgent; KPI profiles are mixed, with potentially high effectiveness once enacted but uniformly low ease of implementation given the need for formal rule changes, negotiations, and common frameworks. These measures rarely unlock flexibility on their own and work best when paired with market/product fixes and clearer risk allocation. Public-support instruments feature prominently in company priorities. Direct support and tax credits can improve competitiveness, revenues, and access to capital, but they raise proportionality and market-distortion concerns and therefore need tight targeting and safeguards. Subsidised feasibility studies perform well across KPIs as a low-risk, low-cost entry point: they build internal awareness and decision quality, yet they are modest at resolving the core economic barriers and should be viewed as a stepping stone toward actual provision.

Company-internal levers and infrastructure. Company-internal measures sit mid-table in priority but can be powerful when chosen deliberately. An incremental investment approach and strategies to mitigate flexibility-cost risk score well; other internal measures (aligning KPIs, adapting procurement to accommodate flexibility, internal shadow pricing, integrating flexibility in strategic plans) are effective but harder to implement because they require process change, capabilities, and leadership buy-in. Infrastructure investments are effective once in place, but hard to push through: *plug-and-play IT modules* perform best overall, while capital-heavy assets (behind-the-meter storage, buffer capacity) tend to score low on ease of implementation and stakeholder acceptance despite strong technical effectiveness.

Information and awareness. This cluster sits in the lower segment of company-derived priorities: companies do not consider these measures critical for unlocking flexibility in the short term. Nevertheless, sector-specific awareness campaigns and showcasing of real industrial cases perform strongly across KPIs, particularly on effectiveness, scalability, and proportionality, without generating heavy implementation burdens or requiring extensive stakeholder involvement. These instruments are easy to roll out and can shift internal perceptions, especially in companies with limited knowledge of flexibility or energy-market functioning in general. However, their effectiveness depends on integration: they work best when paired with more operational tools such as onboarding templates or feasibility studies. As such, companies view information measures less as direct enablers and more as soft accelerators that de-risk early steps and improve decision quality.

Because barrier profiles differ, so should solution emphasis. More mature electro-intensive segments (e.g., parts of non-ferrous) benefit most from clarity on value stacking, proportionate risk sharing, and targeted product tweaks that respect ramp envelopes. Process-sensitive sectors (food and parts of chemicals) need buffering and controls as prerequisites, complemented by calibrated guardrails and clear baselines and penalties. Batch metallurgy in steel benefits from pooling and guardrails, along with incremental, low-risk pathways that acknowledge equipment-wear risks and lean engineering capacity.

1. Introduction

1.1 The Need for Flexibility

The energy system is undergoing a profound transformation. Electrification of sectors such as transport, heating, and industry is accelerating (see Figure 1-1), while an increasing share of variable renewable energy sources (RES) such as wind and solar is being integrated into the grid. These developments are essential for achieving climate neutrality, but they fundamentally alter the way our electricity system needs to operate.

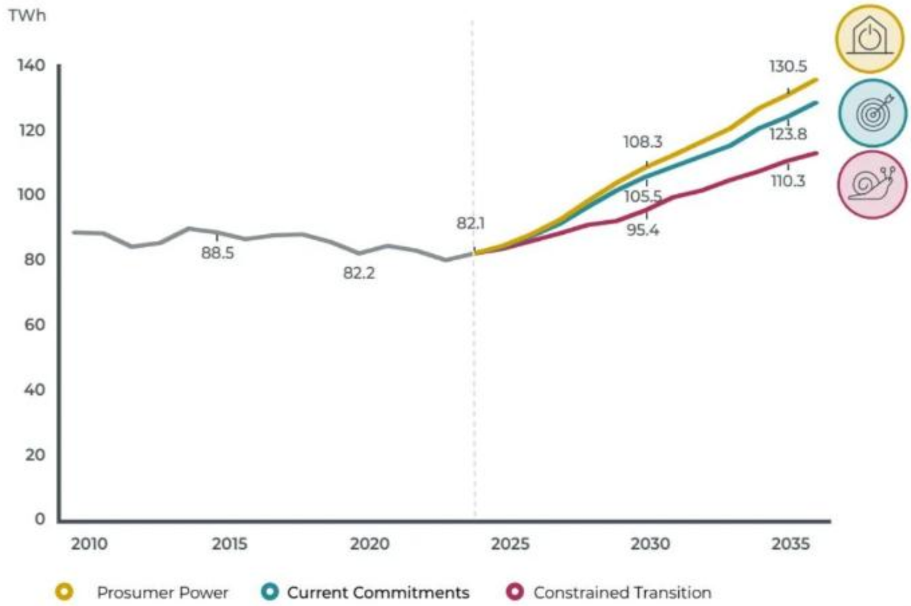

Figure 1-1 Historical and assumed future yearly electricity consumption in Belgium [242]

The acceleration of the energy transition poses challenges for the grid. Grid congestion, voltage fluctuations, and imbalances between supply and demand are becoming more frequent and more difficult to predict. Without timely and cost-effective interventions, the trend of electrification will require significant grid reinforcements and generation capacity additions, both of which entail long lead times and high societal costs.

Flexibility is therefore no longer optional, it is a critical system need. As illustrated in Figure 1-2, Belgium's total flexibility need will increase by at least 2 to 2.5 GW compared to today, primarily due to the growing share of renewables. Importantly, this flexibility is not monolithic. So-called "slow" flexibility (with a response time up to 5 hours) is vital for managing forecast updates and unexpected changes in renewable output a few hours ahead of real time. Elia estimates that the required volume for this type of intraday flexibility will exceed 4 GW by 2036. At the same time, "fast" flexibility (able to respond within 15 minutes) will be needed to absorb real-time deviations and cover sudden events like asset outages or RES forecast errors. These needs are expected to more than double, surpassing 3 GW. Finally, "ramping" flexibility, resources that can react within 5 minutes, will become increasingly valuable, with at least 0.5 GW needed by 2036. These figures underline the scale and diversity of flexibility services that the future system will rely on.

By enabling consumers and producers to adjust their electricity usage or generation in response to system signals, flexibility acts as a buffer between variability and reliability. It ensures a safe grid operation while reducing the cost of the energy transition for society at large.

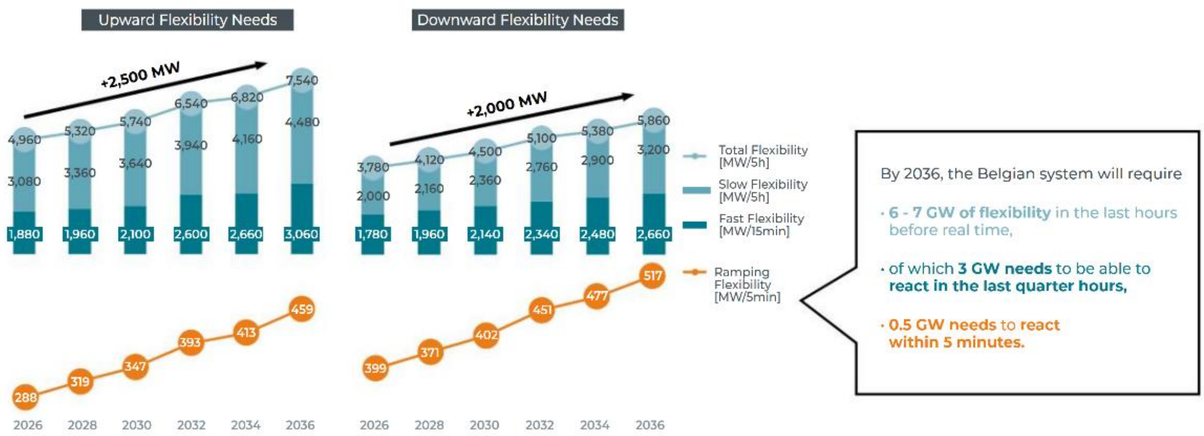

Figure 1-2: Flexibility needs of the system over the coming decade [242]

1.2 The Potential of Industrial Flexibility

Within the broader search for flexibility, the industrial sector holds a uniquely strategic position. Industry accounts for a significant share of total electricity consumption and concentrates this demand in relatively few locations. This combination of scale and controllability makes industrial processes particularly attractive for the provision of system services.

Today, many energy-intensive industrial processes still operate in baseload mode, with limited responsiveness to system or grid conditions. Yet a large part of this demand is technically shiftable or modifiable, whether through short-term process adaptations, buffer usage, or operational planning. This unlockable potential can play a decisive role in delivering cost-efficient adequacy and grid stability.

Projections from Elia's Adequacy and Flexibility Study confirm this role. The electrification of new industrial processes, such as Power-to-Heat, Electric Arc Furnaces (EAF), and data centres, is expected to drive up nominal electricity demand in industry and services by nearly 3 GW by 2036. However, if industrial processes integrate flexibility measures, the net increase in load can be significantly reduced by over 1GW. Even in more constrained scenarios, theoretical increases of 920 MW in 2030 can be reduced to just 540 MW through flexibility activation. Technologies like Power-to-Heat and Electric Arc Furnaces are listed as the key assets to offer 40–80% flexibility.

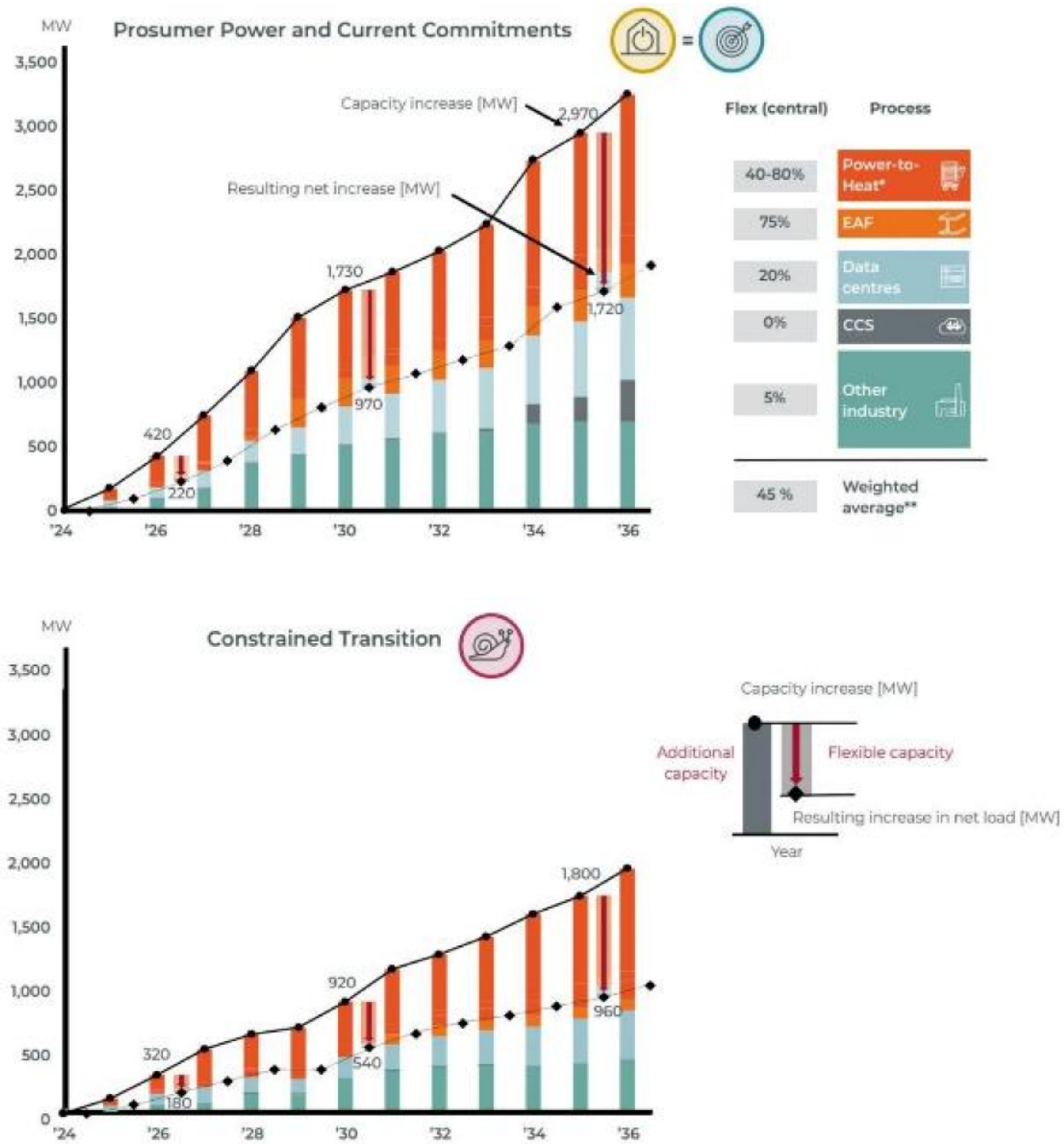

Figure 1-3: Additional nominal capacity and flexibility from new loads, in industry and data centres [242]

1.3 Barriers for Industrial Flexibility

Despite its significant technical and economic potential, industrial flexibility remains underutilised. While some sectors have already integrated demand-side response in their operations, a substantial share of the flexibility that could be delivered in theory does not materialize in practice.

This underutilisation is not surprising when one considers that most industrial systems were never designed with flexibility in mind. Production processes, control systems and operational routines were optimised for efficiency, continuity and output quality—not for dynamic interaction with an external electricity system. As a result, even when flexibility is technically feasible, it often conflicts with how the site was originally configured to operate.

The consequence is a persistent gap between what is theoretically possible and what is actually activated. Bridging this gap requires a clear understanding of the structural barriers that prevent flexibility from being realised—whether they are technical, economic, regulatory, or organisational in nature. Identifying and addressing these barriers is a necessary step toward unlocking industrial flexibility at scale.

1.4 The GALILEO project

The **GALILEO project** aims to accelerate the uptake of industrial flexibility in Belgium by improving awareness, building shared knowledge, and identifying concrete pathways for action. Activating flexibility helps balance the electricity system, reducing the need for additional grid investments and generating social welfare wherever it is cost-effective.

To that end, the GALILEO project assesses the current state of industrial flexibility provision in Belgium and proposes both targeted and systemic solutions to improve the activation of industrial flexibility.

As a first step, the GALILEO project estimates the technical potential of industrial flexibility in Belgium and provides an updated scenario of the impact of industrial flexibility on the Belgium energy system. It thereby sheds a light on the significant gap between the theoretically available technical potential and the actual future flexibility needs that will need to be bridged. It was found that a flexibility potential exists in Belgium's industry, but it is sector-specific and process-dependent. Key flexibility levers are electrolysis (chemicals, non-ferrous), EAFs (steel), process electrification below 500 °C (food), and hyperscale workload shifting (data centers). Interviewed companies indicated multiple barriers that influence the ability to activate flexibility

The purpose of this deliverable is to identify the barriers and propose solutions to unlock the existing flexibility potential.

Chapter 2 evaluates technological, economic, regulatory, organizational, behavioural, informational, and competence-related **barriers** that inhibit the spreading of knowledge and the widescale activation of industrial flexibility. Chapter 3 consequently proposes **solutions** to overcome these barriers. It distinguishes between company-internal solutions, infrastructure solutions, market design solutions, market roles and responsibilities solutions, information and awareness solutions, public support mechanism solutions, and regulatory and legal solutions.

2. Barriers for industrial flexibility

2.1 Introduction

2.1.1 Background

Industrial flexibility is currently unable to reach its full theoretic potential due to several barriers. In this chapter, we aim to identify and prioritize the potential barriers industrial flexibility faces, employing a sector-differentiated approach. The barrier analysis looks at the different industrial sectors involved in the project to better understand which barriers are more universal across sectors and which barriers are more sector specific. Finally, this chapter will also highlight which barriers should be prioritized in the solution development, which will be elaborated in Chapter 3.

2.1.2 Method

The analysis in this chapter is performed in three mains steps, shown in Figure 2-1.

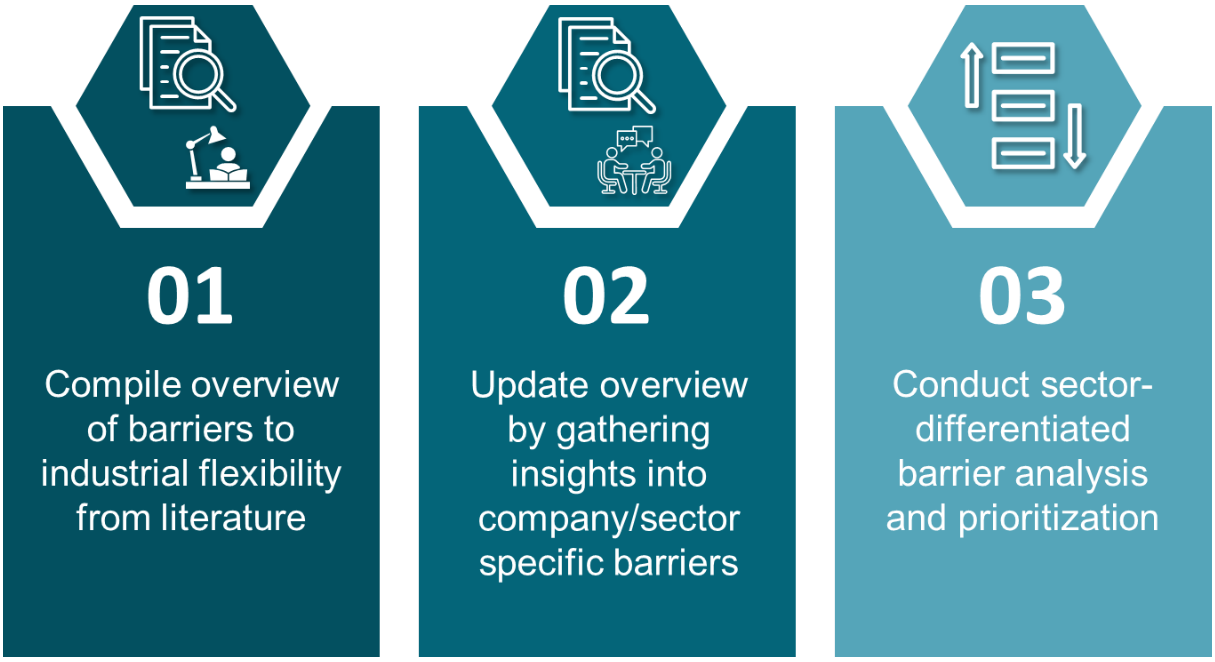

Figure 2-1:Overview of the method used for the analysis of barriers

To identify the reported barriers to industrial flexibility, a structured literature review was conducted. The methodology contained the following steps:

1. **Definition of scope and research objectives.** The aim of the review was to identify, from literature, technical, economic, regulatory, operational, social, and organizational barriers preventing the full exploitation of industrial flexibility. This was guided by the objective set in GALILEO WP1 to '*identify remaining technical, operational, economic, regulatory, social barriers which hamper the exploitation and valorisation of the current and future flexibility potential*' [35].This was guided by the objective set in GALILEO WP1 to '*identify remaining technical, operational, economic, regulatory, social barriers which hamper the exploitation and valorisation of the current and future flexibility potential*' [35].
2. **Design of the approach for collecting the necessary information.** Our approach was based on the concept-centric literature synthesis developed by [36], who propose to group the literature based on central themes and concepts rather than summarize what specific authors say about a certain topic. The theme and concepts we investigated were barriers to industrial flexibility. The information we gathered was then organized in a framework based on the categorization framework developed by [37] where barriers were grouped into technology-related, information, economic, behavioural, organisational, competence-related and awareness categories.
3. **Database and source selection.** The literature review is primarily based on peer-reviewed academic research and technical conference contributions, supplemented by key methodological and conceptual frameworks. The sources can be grouped as follows:
   - *peer-reviewed journal articles* forming the core of the review and selected for their relevance with regard to methodology (e.g., [36], [37]) and theme of industrial flexibility (e.g., [38], [39])
   - *technical conference papers* providing sector-specific insights (e.g., [40], [41])
   - *review papers* offering a structured review of the relevant literature (e.g., [42], [43])
4. **Keywords.** The main keywords that were used in the search were 'industrial flexibility', 'barriers', 'demand-response' and synonyms of these words.

5. **Inclusion and exclusion criteria.** Inclusion criteria included articles focusing on obstacles to industrial demand-side flexibility, published after 2001 and peer-reviewed or high-quality literature. Sources that focused solely on residential or non-industrial sectors or that were unrelated to energy system flexibility were excluded.
6. **Screening and selection.** Titles and abstracts were screened, when deemed relevant the full text was analysed. In total, ninety-two references were selected.

As shown in Figure 2-1, in a second step the barrier framework and literature were complemented by insights gathered from workshops with the industrial GALILEO partners. This allowed for the validation of the literature-based barriers (those relevant for the specific Belgian industrial sectors in the GALILEO project) and enrichment of the literature with practical company-level experiences.

Next to updating the barrier overview, barriers are ranked according to their relevance for companies and industrial sectors. This exercise is the third and final step in the analysis.

2.2 Barrier categorization

Based on literature, we distinguish a total of seven categories of barriers. Figure 2-2 provides a graphical overview of these categories. The definitions are given below the figure.

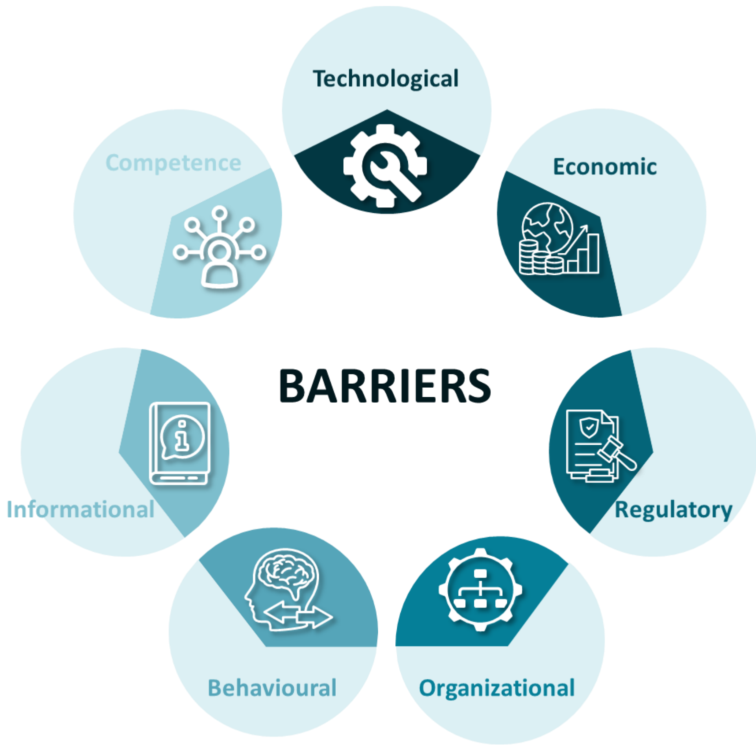

Figure 2-2: Overview of barrier categories

Technological barriers arise from limitations in technical infrastructure and production process constraints that prevent the effective implementation of flexibility provision.

Economic barriers can be internal as well as external. They are linked to financial constraints, such as high investment and financing costs, uncertain returns, limited financial incentives, and high operational expenses, that hinder companies from providing flexibility.

Regulatory barriers are legal and policy-related obstacles, including complex, inconsistent, or restrictive regulations which create uncertainty, slow down initiatives or prevent companies from providing flexibility.

Organizational barriers are caused by internal company structures, decision-making processes, and management priorities which limit the provision of flexibility due to competing interests, lack of coordination, or resource allocation issues.

Behavioural barriers are related to psychological and cultural resistance within organizations, including scepticism, reluctance to change, and preference for established practices, that impede the provision of flexibility.

Informational barriers entail lack of access to, understanding of, or transparency in relevant data, market signals, and regulatory requirements, which prevents companies from making informed decisions about flexibility provision.

Competence-related barriers are defined by deficiencies in knowledge, skills, or expertise within an organization that prevent the effective identification, implementation, and management of flexibility opportunities.

2.3 Overview of barriers

Figure 2-3 provides an overview of the number of barriers per category. These barriers were collected from literature and the interactions with the GALILEO project companies.

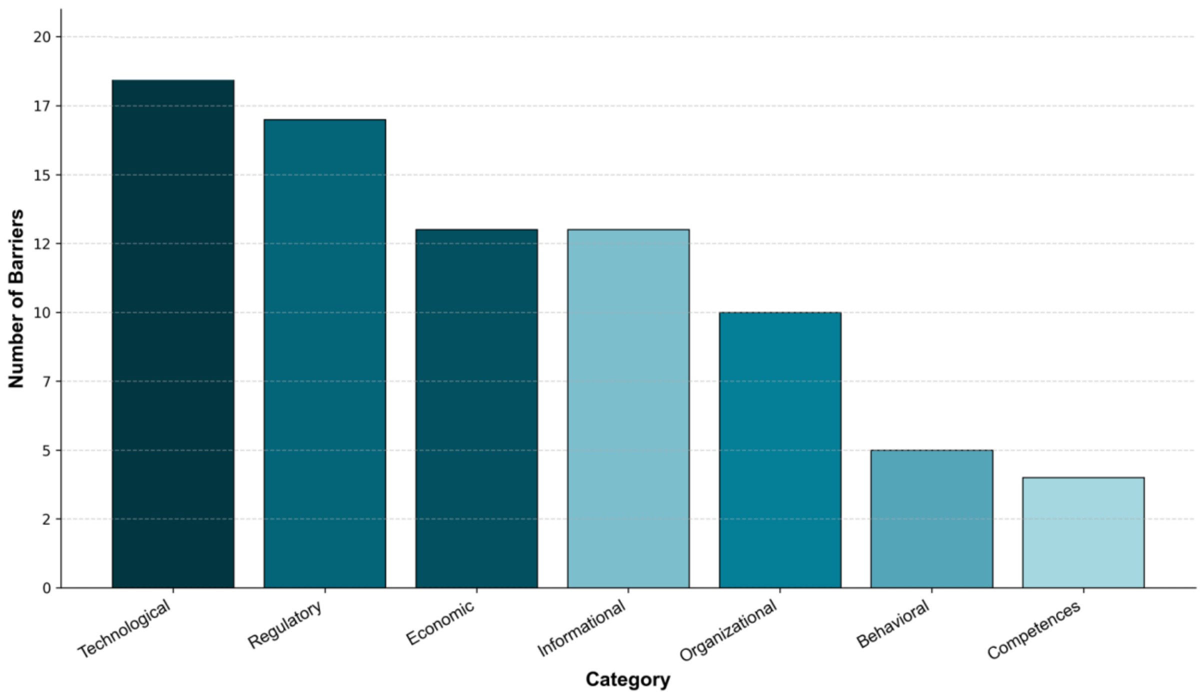

Figure 2-3: Numbers of barriers found per barrier category

In total, more than eighty distinct barriers were identified. The highest concentration of barriers lies in the technological and regulatory domains. The economic and informational categories also contain more than ten barriers each. In contrast, the organisational, behavioural, and competence-related categories contain fewer barriers.

It is important to note that the number of identified barriers in a given category does not necessarily reflect its overall importance or impact. Some categories—such as behavioural or organisational—may contain fewer individual barriers, but these can be highly structural or cross-cutting in nature. Conversely, categories with many smaller, specific barriers (e.g.

technological) may still be more straightforward to address in practice. The number of barriers thus reflects the diversity of issues within a category, not a ranking of their criticality. This is exactly where the interviews and workshops contribute: they help assess real-world materiality and prioritise cross-cutting barriers regardless of raw counts.

In what follows, we will describe the different barriers per barrier category. A structured overview of the barriers and references can be found in Table 2-1 to Table 2-7.

2.3.1 Technological barriers

We have observed 20 different technological barriers. These can be categorized into two distinct groups based on their origin: internal and external technological constraints.

- **Internal technological constraints** stem directly from within industrial operations, including potential disruptions in production, capacity limitations (both production and storage), complexity arising from interconnected production steps, the risk of increased equipment wear, and maintaining product quality standards.
- **External technological constraints** refer to challenges outside the production facility, such as restrictions imposed by inadequate electricity grid infrastructure (e.g., existing congestion or insufficient capacity) and IT-related barriers, including high implementation complexity, data security vulnerabilities, limited standardization, and interoperability issues.

Figure 2-4 presents an overview of the key technological barriers to provide industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-1. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

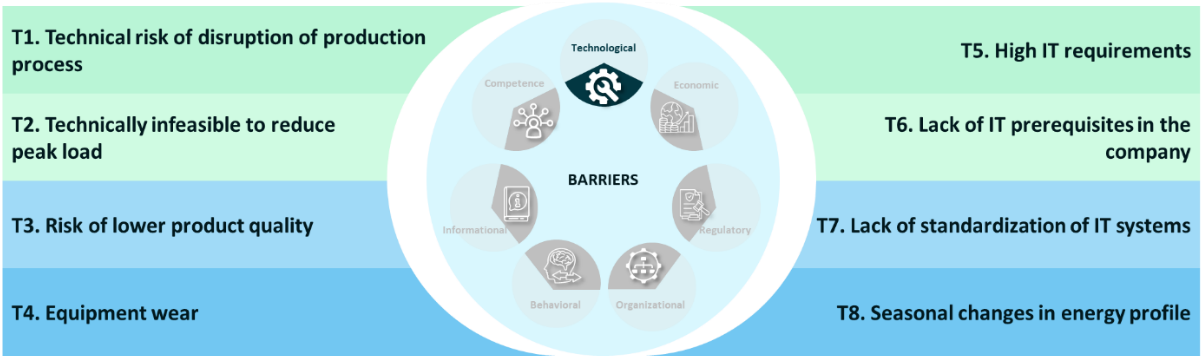

Figure 2-4: Overview of technological barriers

Table 2-1: Structured overview of technological barriers

Index	Barrier name	Barrier description	References
T1	Technical risk of disruption of production process	An intervention in the main production process might be considered too risky by some process operators and companies. This intervention could consist of an interruption of the production process or a deviation in the originally planned power consumption. These actions can introduce instability into tightly controlled processes, especially when newly developed technologies (e.g., automated demand-response systems, external control software, or AI-based optimization tools) are used that have not yet been fully tested in the specific industrial setting. In addition, these interventions can reduce the ability of operators to diagnose and resolve	[38], [39], [40], [41], [42], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56]

		process issues, because the system may no longer follow the standard process states and alarm flows. This so-called loss of troubleshooting ability makes it harder to trace root causes, delays corrective action, and increases operational uncertainty.	
T2	Technically infeasible to reduce peak load	Certain industrial processes are technically unable to flexibly adjust their electricity demand due to intrinsic operational constraints. These constraints include a lack of excess production capacity, the necessity to maintain stable and optimal operating conditions, and insufficient process responsiveness to meet rapid activation requirements.	[38], [39], [45], [52], [56], [57], [58], [59], [60], [61]
T2.1	Production capacity limitations	If the existing capacity already runs near 100%, it can be difficult to provide flexibility as production capacity may need to be increased to allow for flexible production, e.g., to make up for the time lost during the DR event.	[61]
T2.2	Storage capacity limitations	Sufficient storage capacity might be needed upstream (when production capacity is temporarily decreased) or downstream (when production capacity is temporarily increased) of the industrial process. This storage capacity can be both physical or electrical storage.	[61]
T2.3	Space requirements	If providing flexibility requires increased production and/or storage capacity, it could be hindered by space limitations that impede increasing this capacity.	[61]
T2.4	Up-/Downstream process constraints	Interconnected production steps may restrict flexibility provision since altering one production step can negatively impact preceding or subsequent processes, requiring continuous or synchronized operation.	[61]
T2.5	Existing electricity grid is already congested	Providing additional flexibility may require expanding or intensifying electricity usage. However, grid operators may restrict additional electrical load if the existing local grid infrastructure is already operating at or near maximum capacity.	[62]
T2.6	Constraints to upgrade grid capacity	Companies willing to provide flexibility through electrification or capacity expansions face a barrier if the necessary grid infrastructure has not yet been developed. Planned grid expansions or upgrades may take substantial time to materialize, delaying or entirely preventing the company's participation in flexibility markets.	[62]
T2.7	Complexity of the industrial process	The process is too complex to modify, or the manufacturer cannot guarantee the safe functioning of the installation under certain conditions (e.g., more full load hours)	[62]
T3	Risk of lower product quality	By creating variations in a production process (e.g., duration of a process, flow rates), there is a risk of lower product quality. As product quality	[38], [39], [44], [45],

		is often very important, companies prefer keeping production processes stable.	[52], [56], [63], [64]
T4	Equipment wear	More frequent and/or more extensive up/down ramping of production processes can potentially damage machinery and accelerate equipment wear.	[61]
T5	High IT requirements	Implementing demand-response measures requires sophisticated IT solutions characterized by high speed, accuracy, and automation. Companies face strict external demands, especially when providing ancillary services, that necessitate reliable IT systems capable of rapidly processing extensive, real-time data streams. Additionally, these systems must manage potential disruptions or faults promptly to ensure production continuity.	[38], [45], [52], [65], [66], [67]
T5.1	High effort and complexity within the IT system	Developing, deploying, and maintaining the IT infrastructure for flexible load management involves considerable internal efforts and complexity. Companies must significantly adapt their existing production automation systems, integrate new communication protocols, and create customized interfaces to interact seamlessly with external flexibility markets or aggregators. The extensive data handling, combined with strict real-time processing constraints, further increases the complexity and cost.	[38], [43], [45], [46], [51], [68], [69], [70], [71], [72]
T5.2	Lack of computational capacity	To be able to provide flexibility, companies have to also be able to process a large volume of data. They may lack the computational capacity for the optimization of demand-response measures and it can be a challenge to acquire the required computational capacity at an acceptable cost.	[38], [42], [43], [73]
T5.3	IT and data security	Proper handling of sensitive data is a critical factor in an IT system designed for flexibility. For instance, many demand-response programs require interfaces to external partners. Therefore, these external interfaces and the IT system itself could be vulnerable to external manipulation or attacks. Depending on the company, data describing flexible loads is highly sensitive, as it may contain information on the amount of product orders of the company.	[38], [39], [42], [43], [56], [73], [74], [75], [76], [77], [78], [79], [80]
T6	Lack of IT prerequisites and appropriate control infrastructure	Many industrial companies face limitations in their existing IT systems, meters, and control infrastructure, which are not designed to support flexibility provision. For example, machines often lack fully automated interfaces or connectivity with other systems, making real-time control or coordination difficult. Furthermore, monitoring and analysis tools may not collect the data required to assess or implement flexibility measures. In addition, appropriate control and communication technologies are often unavailable or insufficiently mature. This	[38], [40], [43], [72], [73], [75], [78], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91] [59], [60], [61], [62]

		includes metering infrastructure with limited bandwidth or signaling capabilities, and the absence of standardized, off-the-shelf equipment to meet the technical demands of advanced demand-response participation. As a result, companies must often resort to customized and costly solutions, further complicating the business case for flexibility.	
T7	Lack of standardization and interoperability of IT systems	The absence of common standards for IT hardware, software, and communication protocols forces companies to rely on tailor-made solutions. This also limits interoperability, as systems from different providers often fail to integrate smoothly. As a result, this barrier hinders smooth information exchange, limits flexibility in partner choice.	[38], [43], [48], [51], [57], [71], [73], [74], [77], [84], [92], [93], [94], [95], [66], [67]
T8	Seasonal changes in energy profile	Seasonal changes in energy profile can make it harder to participate in flexibility markets as the available flexibility capacity differs from one month to another.	[62]

2.3.2 Economic barriers

We have identified multiple economic barriers that negatively affect the attractiveness of industrial flexibility. These economic factors broadly fit into two categories: (i) Insufficient financial incentives and revenue risks: in many firms electricity costs are a small share of total production costs; expected returns from flexibility participation are weak; spot-market price spreads are narrow; profitability in ancillary service markets has declined; and net revenues remain uncertain due to activation/volume risk, baseline and settlement rules, interactions with existing supply contracts, and exposure to non-delivery penalties. (ii) Investment and operating cost burdens: flexibility often requires high upfront CAPEX for metering, controls and IT; limited access to capital (particularly for SMEs); additional operating expenses linked to planning, coordinating and executing activations; extended payback periods; and potential interference with production targets and delivery obligations.

Figure 2-5 gives a graphical overview of the economic barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is given in Table 2-2. In the figure, only the main barriers are shown. However, some barriers can be further divided into sub-barriers. These are discussed further down in the table.

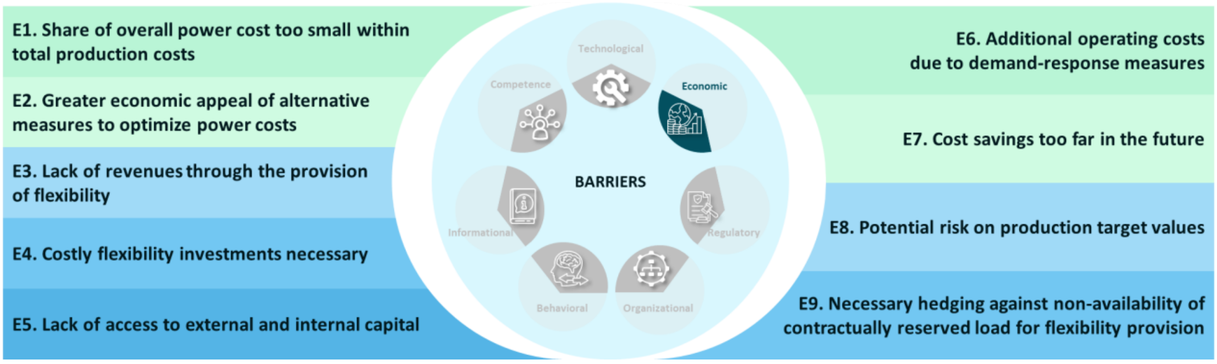

Figure 2-5: Overview of economic barriers

Table 2-2: Structured overview of economic barriers

Index	Barrier name	Barrier description	References
E1	Share of overall energy cost too small within total production costs	When the share of overall energy costs is too small within the total production costs, companies mostly do not even consider implementing flexibility in production as other production cost reduction initiatives are relatively more important.	[38], [53], [54], [88], [96], [97], [98]
E2	Greater economic appeal of alternative measures to optimize energy costs	If alternative measures to optimize power demand can reduce energy costs more substantially than the provision of flexibility can, companies will prefer those measures.	[38]
E3	Lack of revenues through the provision of flexibility	When the potential revenues from participating in flexibility markets are insufficient, companies typically show low interest in developing demand-response capabilities.	[38], [40], [43], [48], [50], [52], [54], [68], [74], [75], [77], [78], [85], [90], [91], [92], [93], [97], [99], [100], [101]

E3.1	Energy cost savings through flexibility provision are low	Cost savings from flexibility provision measures are often minimal relative to the costs and efforts required to implement and maintain these measures, making the financial case less appealing.	[38], [39], [68], [80], [81], [85], [86], [99]
E3.2	Price-spreads on spot markets too small	Limited price differences between peak and off-peak periods on spot markets reduce potential savings for companies purchasing electricity dynamically, diminishing the financial attractiveness of demand-response.	[38], [49], [55], [81], [91], [93], [102]
E3.3	Uncertain profitability in ancillary service markets	Ancillary service markets are evolving rapidly, but their long-term revenue potential remains uncertain for industrial flexibility providers. While some market segments (e.g. FCR) have shown signs of declining profitability in mature phases, this is not a uniform trend across all services or countries. The ongoing integration of balancing markets at the European level (e.g. through PICASSO and MARI platforms) is expected to harmonize product definitions and increase liquidity, which may exert downward pressure on prices over time. However, the net effect of these reforms, in combination with changes in system needs, entry of new technologies (e.g. batteries), and future market designs, is still difficult to predict. As such, companies face a high degree of investment uncertainty: the current lack of stable, long-term revenue expectations is often cited as a key barrier to engaging in ancillary service markets.	[38], [49], [50], [80], [103], [104], [105]
E4	Costly flexibility investments necessary	Initial investments required for enabling flexibility, such as modernizing equipment, enhancing production capacity, or infrastructure upgrades (e.g. reinforcing the site's electrical connection), are significant and often less attractive compared to alternative investments like energy efficiency improvements.	[38], [39], [40], [42], [43], [50], [51], [53], [73], [75], [81], [83], [84], [99], [101], [106]
E4.1	High IT investments necessary	Substantial upfront investments in IT infrastructure, such as automated control systems and external communication interfaces, typically constitute the most significant part of total flexibility-enabling investment costs.	[38], [39], [40], [51], [53], [74], [76], [80], [83], [85], [95], [101], [106], [107], [108], [109]
E5	Lack of access to external and internal capital	Companies often lack the necessary access to capital (both internal and external) to realize the needed investments. For small and medium-sized companies, in particular, the required investments may be too high compared to their available capital.	[38], [39], [43], [53]
E6	Additional operating costs due to demand-response measures	Providing flexibility can increase operational costs, such as maintenance costs, information and transaction costs and costs associated with the integration of demand-response processes in existing systems of a company. Furthermore, demand-response measures may lead to higher expenditures on personnel for re-scheduling production and increased hourly wages for night-shifts, weekends or holidays. Moreover, even if companies involve external service providers to	[38], [39], [40], [42], [52], [53], [54], [63], [69], [75], [81], [97], [106], [108], [109], [110]

		contribute expertise in providing flexibility, companies still need personnel to manage the service provider.	
E7	Cost savings too far in the future	Provision of flexibility is often only profitable in the long term. As a result, the payback period is often too long, making investment less attractive.	[38], [39], [53], [77], [85]
E8	Potential risk on production target values	Flexibility measures risk compromising critical production, the set production targets and delivery commitments. Companies may therefore hesitate to engage in flexibility actions due to potential conflicts with agreed delivery schedules and the associated risks of breaching supply contracts.	[38], [39], [52], [80], [99], [106]
E9	Necessary hedging against non-availability of contractually reserved load for flexibility provision	Companies face financial risks if unable to deliver flexibility when contractually obligated, requiring costly hedging strategies or financial instruments to manage the risk of contractual penalties.	[38], [83], [85], [91]

2.3.3 Regulatory barriers

When it comes to regulatory barriers, a complex and sometimes contradictory regulatory framework makes it difficult for companies to navigate flexibility provision programs effectively.

Several layers of energy and climate legislation influence the regulatory environment in which Belgian industries operate. At EU level, directives such as the Electricity Directive (EU) 2019/944, the Energy Efficiency Directive (EU) 2023/1791 and the Clean Industrial Deal set the overarching framework for flexibility and energy use in industry. These are complemented or complicated by national and regional implementations, for instance through Belgian grid fee reforms or capacity remuneration rules.

Several tensions emerge from this complex layering of regulations. For instance, while the Electricity Directive (EU) 2019/944 mandates non-discriminatory aggregation (Art. 17) and dynamic price entitlement for customers with smart meters (Art. 11), national prequalification/metering rules and Closed Distribution System (CDS) data-access arrangements can in practice delay or exclude behind-the-meter industrial flexibility from aFRR/mFRR participation. Finally, the Energy Efficiency Directive (EU) 2023/1791 (Arts. 3 and 11) elevates ‘Energy Efficiency First’ obligations; companies report that these requirements can conflict in operation with certain DR strategies that temporarily deviate from instantaneous efficiency—best framed as a policy trade-off rather than a legal incompatibility.

Inconsistent grid fee structures, lack of access to time-variable electricity prices, and restrictive prequalification requirements for participation in flexibility programs create significant barriers. Additionally, frequent changes in energy regulations lead to uncertainty, discouraging long-term investment in flexibility.

Figure 2-6 gives a graphical overview of the regulatory barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-3. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

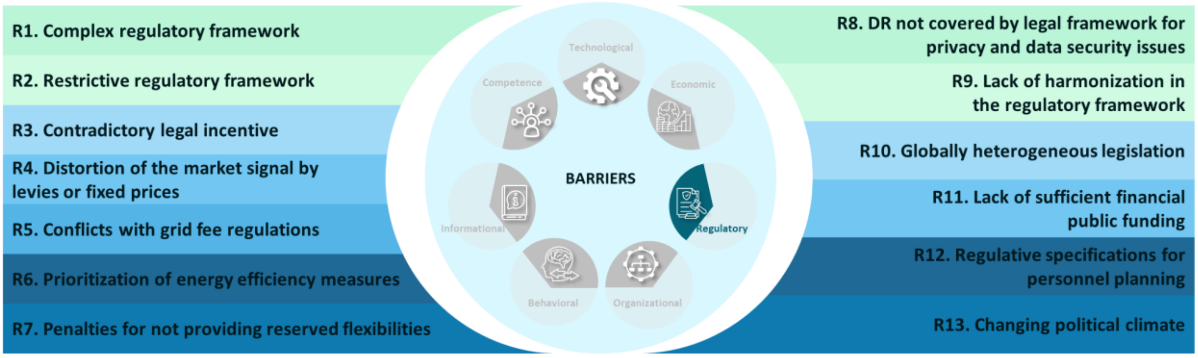

Figure 2-6: Overview of regulatory barriers

Table 2-3: Structured overview of regulatory barriers

Index	Barrier name	Barrier description	References
R1	Complex regulatory framework	The regulatory framework for industrial flexibility spans multiple layers — EU, national, and regional — leading to complexity in terms of roles, data requirements, participation procedures, and compliance obligations. For instance, while Directive 2019/944 (Art. 17) mandates non-discriminatory access for independent aggregators, Belgium lacks harmonised contractual models between aggregators and BRPs, creating unclear liabilities and coordination burdens. In addition, there are no well-defined frameworks for non-firm grid access (Regulation 2019/943, Art. 32), and Closed Distribution Systems (CDS) (Art. 38) remain only partially integrated into DR market schemes, complicating market access for behind-the-meter industrial assets. In addition, flexibility that requires new storage or higher rated capacity often triggers environmental (and sometimes spatial) permitting or permit-amendment procedures. In Belgium this sits under the regional systems and may include EIA screening for Annex-II-type projects (Directive 2011/92/EU as amended by 2014/52/EU), plus emissions compliance where applicable (e.g. MCP Directive 2015/2193 for 1–50 MWth and IED 2010/75/EU for >50 MWth combustion). These threshold-based triggers and multi-step procedures introduce lead-time and outcome uncertainty that can delay or deter deployment of flexibility assets.	[38], [39], [74], [81], [111], [112]
R2	Restrictive regulatory framework	Certain behind-the-meter flexibility assets, including those located within Closed Distribution Systems (CDS) or private grids, are often de facto excluded from ancillary service markets. This results not from explicit legal prohibitions, but from restrictive prequalification requirements, data access limitations, and unclear role definitions. For instance, the inability to provide real-time metering data validated by the public DSO, or the absence of clear aggregation pathways within CDS, can effectively prevent	[38], [39], [43], [50], [51], [55], [65], [80], [100], [109], [113]

		participation—despite EU-level provisions requiring non-discriminatory market access for demand response.	
R2.1	Lack of access to time-variable electricity prices	It is difficult for companies to access time-variable electricity prices, e.g., by directly participating in energy-only markets. For trading energy products in energy-only markets like the EPEX Spot, companies usually need a broker for market access (which then also comes with a cost).	[38], [50], [54], [58], [74], [80], [81], [111]
R2.2	High costs and effort for prequalification	Participation in ancillary service markets requires costly and complex prequalification processes, whereby companies must prove technical capabilities upfront. Although simplifications are anticipated, the current administrative burden remains significant.	[38], [40], [80], [98], [114]
R2.3	Flexibility product design	Certain market design characteristics, such as response time requirements and duration of activation, reduce the suitability and attractiveness of industrial processes for flexibility market participation.	[41], [43], [50], [52], [54], [55], [60], [65], [67], [75], [80], [81], [85], [91], [102], [104], [105], [109], [110], [115], [116], [117], [118]
R3	Contradictory legal incentives	Certain EU and national policy objectives conflict in practice, forcing companies to make trade-offs between compliance pathways. For example, Regulation (EU) 2019/943 (Art. 18(7)) states that network tariffs should not disincentivise demand response, yet in Belgium the capacity-based distribution tariff penalises brief peak loads — including those caused by flexible consumption responding to market signals — thus undermining the incentive to participate in DR markets. Another case is the tension between the Energy Efficiency Directive (2023/1791) — which promotes continuous optimisation and energy management (e.g. via ISO 50001 and EMS obligations) — and the Electricity Directive (2019/944), which incentivises load shifting and demand variability. Participating in flexibility markets may require temporary deviations from efficient operating points, potentially jeopardising efficiency targets, certification, or compliance with voluntary energy policy agreements.	[38]
R4	Distortion of the market signal by levies or fixed prices	Fixed levies and charges distort electricity price signals, preventing companies, particularly those with self-generation capacity, from fully benefiting from dynamic or negative market prices. This distortion undermines incentives for flexibility.	[38], [43], [51], [53], [59], [60], [80], [85], [95], [102], [114], [117], [119], [120]
R5	Conflicts with grid fee regulations	Companies seeking grid fee reductions through peak load management risk losing financial advantages if participating in additional flexibility programs increases	[38], [59], [98]

		their registered peak load, creating conflicting incentives.	
R6	Prioritization of energy efficiency measures	Flexibility measures may require intentional deviations from optimal operating points, which can reduce short-term energy efficiency. This creates tensions with regulatory or certified energy efficiency obligations, including those under national implementations of the EU Energy Efficiency Directive (e.g. audit requirements, annual savings targets) and international standards like ISO 50001. Participating in demand response often requires deviating from optimal operating points, which may reduce short-term energy efficiency. This can jeopardize compliance with legally binding energy-efficiency targets or voluntary agreements (e.g., Energy Policy Agreements), potentially resulting in penalties, loss of certification, or reputational risks.	[38], [51], [90] [54], [68], [98]
R7	Penalties for not providing reserved flexibilities	When companies participate in balancing markets by reserving flexible capacity (e.g. in aFRR or mFRR), they are legally obligated to provide the committed flexibility when activated. These obligations are defined in the market design rules and regulatory frameworks established by the TSO and approved by the national regulator. If the company fails to deliver the reserved flexibility, penalty mechanisms apply. These are not voluntary contractual penalties, but enforced compliance measures embedded in the balancing market regulation (e.g. imbalance settlement, contractual clawbacks, or fines).	[38], [45], [65], [85], [91], [104], [115], [117]
R8	DR not covered by legal framework for privacy and data security issues	Current DR regulations inadequately address privacy and data security concerns, leaving ambiguity about responsibilities regarding sensitive metering data and interactions with third parties like aggregators.	[38], [74], [80], [114]
R9	Lack of harmonization in the regulatory framework	While DR is supported by EU legislation, its integration into existing energy market structures, particularly those around BRP obligations and grid codes, remains incomplete. For example, Belgium does not yet have a fully harmonised framework that defines how independent aggregators interact with supplier-BRPs, particularly regarding volume reconciliation, imbalance responsibility, and data validation.	[38], [67], [74], [77], [91]
R10	Globally heterogeneous legislation	Differences in national implementations of DR legislation across Europe increase complexity, administrative burdens, and resource requirements for globally operating companies, hindering effective DR participation.	[38], [42], [52], [80], [91], [114]
R11	Lack of sufficient financial public funding	Industrial participation in demand response is often limited by the lack of targeted public funding to support both investment and innovation. On the one hand, investment support schemes (e.g. national or regional subsidies) for enabling infrastructure — such as advanced metering, process automation, or storage — are often unavailable or not tailored to DR applications. On the other hand, innovation and demonstration funding (e.g. via Horizon Europe, national innovation	[57], [104], [114], [119]

		agencies, or ETF) may not prioritise industrial flexibility or may exclude certain sectors or asset types.	
R12	Regulative specifications for personnel planning	Regulatory obligations concerning personnel scheduling complicate companies' ability to spontaneously adjust workforce deployment in response to flexibility requests.	[61]
R13	Changing political climate	Frequent policy changes driven by political shifts create regulatory uncertainty, complicating companies' long-term investment decisions and strategic planning in demand-response activities.	[62]

2.3.4 Organizational barriers

We have observed various organizational barriers that hinder industrial flexibility, which emerge from multiple layers and parts of an organization. These barriers range from overarching aspects such as corporate vision, mission, and strategic convictions, down to detailed operational factors. High-level barriers include limited strategic importance placed on energy management by top management, internal guidelines favoring short- to medium-term projects, and insufficient integration of sustainability or flexibility objectives into the organizational mission. On a more detailed operational level, barriers involve restrictive company Key Performance Indicators (KPI), increased workloads and complexity for employees, complicated decision-making processes involving multiple stakeholders, and energy procurement policies.

Figure 2-7 gives a graphical overview of the organisational barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-4. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

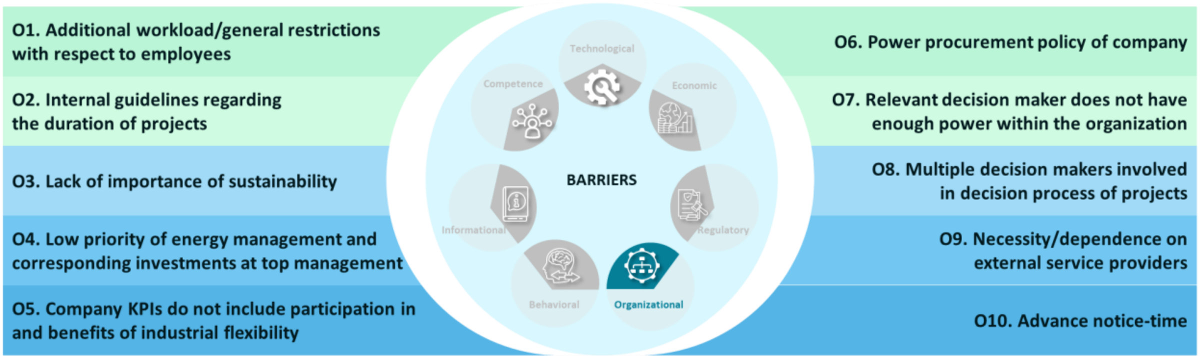

Figure 2-7: Overview of organizational barriers

Table 2-4: Structured overview of organizational barriers

Index	Barrier name	Barrier description	References
O1	Additional workload employee related restrictions	Introducing flexibility measures can increase operational workload due to newly required monitoring tasks, manual activations, override procedures, or adjustments in planning and maintenance routines. The complexity of these additional workflows depends on the existing work organisation, available digital tools, and the qualification level of staff. In addition, companies	[38], [39], [54], [81], [86], [97]

		may face employee-related constraints, such as collective labour agreements, minimum staffing requirements, fixed shift planning, or internal HR rules, which can limit the ability to implement operational changes at short notice, especially outside of normal working hours. In addition, companies may face employee-related constraints, such as collective labour agreements, minimum staffing requirements, fixed shift planning, or internal HR rules, which can limit the ability to implement operational changes at short notice, especially outside of normal working hours.	
O2	Internal guidelines regarding the duration of projects	In many companies, internal procedures and investment guidelines favour short- to medium-term projects (typically 3 to 5 years) with predictable outcomes. These internal constraints are often shaped by strategic planning cycles, governance structures, or risk aversion in decision-making committees. Flexibility projects, by contrast, may involve longer payback periods (10–12 years) and greater uncertainty, which can clash with internal project evaluation criteria and result in the rejection or deprioritisation of such initiatives — regardless of their systemic value or long-term potential.	[38]
O3	Sustainability benefits rarely decisive in flexibility investment decisions	Although industrial flexibility can contribute to sustainability objectives, for example by enabling greater self-consumption of on-site renewable generation, reducing peak demand, or facilitating integration of variable renewables in the grid, these benefits are often indirect, long-term, or system-level in nature. As a result, they carry little weight in internal investment decisions, which tend to prioritise short-term economic returns.	[38], [45], [105]
O4	Low priority of energy management and corresponding investments at top management	Flexibility investments often lack priority at the executive level, especially when managers perceive technical or financial risks outweighing potential benefits.	[38], [39], [43], [53], [55], [70], [81], [96], [110]
O5	Company KPIs do not include participation in and benefits of industrial flexibility	Decision-makers (e.g., plant managers) have no incentive to support flexibility initiatives, as their performance metrics (KPIs) may be negatively impacted by temporary production reductions or disruptions.	[62]
O6	Energy procurement policy of company	Centralized corporate energy procurement can limit site-level incentives and autonomy to participate in flexibility programs, as local facilities may lack direct economic signals or authority for decision-making.	[38], [58]
O7	Limited organisational influence of flexibility advocates	Even when companies acknowledge the potential of flexibility, the employees or departments tasked with exploring it often lack the budget authority, strategic visibility, or cross-departmental reach to move initiatives forward.	[38], [43], [44]

O8	Multiple decision makers involved in decision process of projects	Involvement of multiple departments and decision-makers in flexibility projects leads to complex, prolonged, and costly decision-making processes, potentially delaying or preventing implementation.	[38], [53], [54]
O9	Dependency on external service providers can limit strategic flexibility development	Companies often rely on external service providers or aggregators to implement flexibility solutions, particularly for IT integration, control systems, and market access. While this can unlock initial flexibility potential, strong dependence on a single provider, especially when using proprietary or non-interoperable system, can limit future adaptability. Examples include difficulties in integrating additional assets, switching market participation models (e.g. from balancing to capacity markets), or combining services across multiple sites or aggregators. Moreover, strong outsourcing can slow internal knowledge development, reducing the company's ability to identify or pursue new flexibility opportunities in the future.	[38]
O10	Advance-notice-time	Many industrial processes require a minimum advance notice period to adjust production schedules, coordinate shift planning, or prepare technical systems for activation. If flexibility signals (e.g. price spikes, activation requests) are received too close to real-time, companies may be unable to respond, not because of unwillingness or lack of capacity, but because the operational lead time is too short to reconfigure production safely or efficiently.	[61]

2.3.5 Behavioural barriers

We have identified various behavioural barriers impacting industrial flexibility, which primarily relate to the perception and behaviour of two stakeholder groups: internal stakeholders (employees) and external stakeholders (general public).

- For internal stakeholders, employees often exhibit resistance or reluctance to adopt new flexible work processes due to insufficient awareness of underlying motivations, concerns about inconvenience, habitual attachment to existing workflows and scepticism towards fully automated solutions.
- Externally, public perception and opposition can also form significant barriers, particularly when flexibility measures involve constructing new installations, leading to concerns over perceived nuisances among local residents.

Figure 2-8 gives a graphical overview of the behavioural barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-5. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

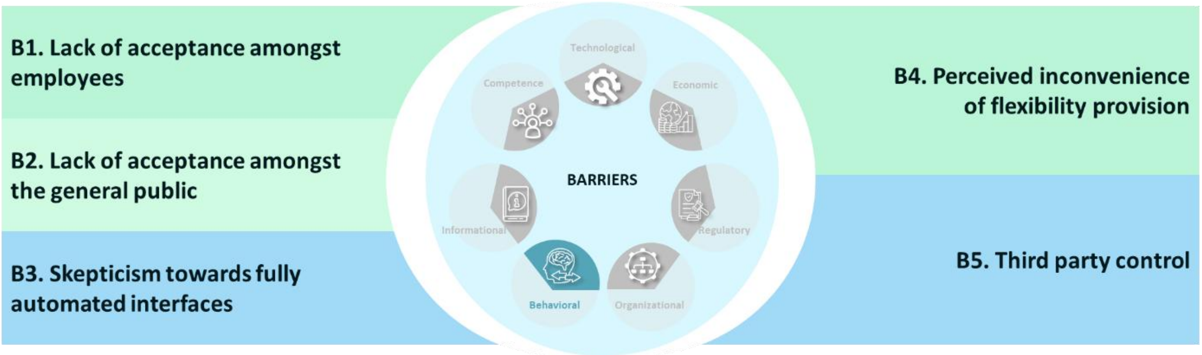

Figure 2-8: Overview of behavioural barriers

Table 2-5: Structured overview of behavioural barriers

Index	Barrier name	Barrier description	References
B1	Lack of acceptance amongst employees	Employees may resist adopting flexibility measures due to insufficient communication about their purpose or scepticism towards external experts involved. Additionally, employees may perceive new processes as risky, fearing potential malfunctions and workflow disruptions.	[38], [53], [91], [106], [110]
B2	Lack of acceptance amongst the general public	Local residents may oppose new installations related to flexibility projects, citing perceived nuisances such as noise, odors, or visual disturbances.	[62]
B3	Scepticism towards fully automated interfaces	Companies are often reluctant to fully automate flexibility interventions, perceiving significant operational risks. They prefer semi-automated solutions retaining human oversight to ensure control over critical production processes.	[43], [53], [65], [74], [77], [79], [86], [106], [111], [121]
B4	Perceived inconvenience of DR provision	Management and employees may perceive flexibility programs as inconvenient due to required changes in established workflows or disruptions to core production objectives, leading to resistance rooted in comfort loss or ingrained habits.	[38], [40], [43], [53], [72], [80], [81], [82], [88], [92], [99], [101], [105], [106], [120], [121]
B5	Third party control	Participation in flexibility programs can create employee and management concerns about dependence on external automated signals (e.g., from grid operators), fearing possible production disruptions, incorrect instructions, or increased equipment wear.	[61]

2.3.6 Informational barriers

Informational barriers extend to multiple areas. Many companies lack transparency regarding flexibility opportunities and are unaware of the potential financial and operational benefits.

Information asymmetry in energy markets, uncertainty about future regulatory changes, and lack of standardized methods for calculating demand response (DR) baselines make participation challenging. High costs and uncertainties in evaluating DR projects further deter companies from adopting flexibility measures.

Figure 2-9 gives a graphical overview of the informational barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-6. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

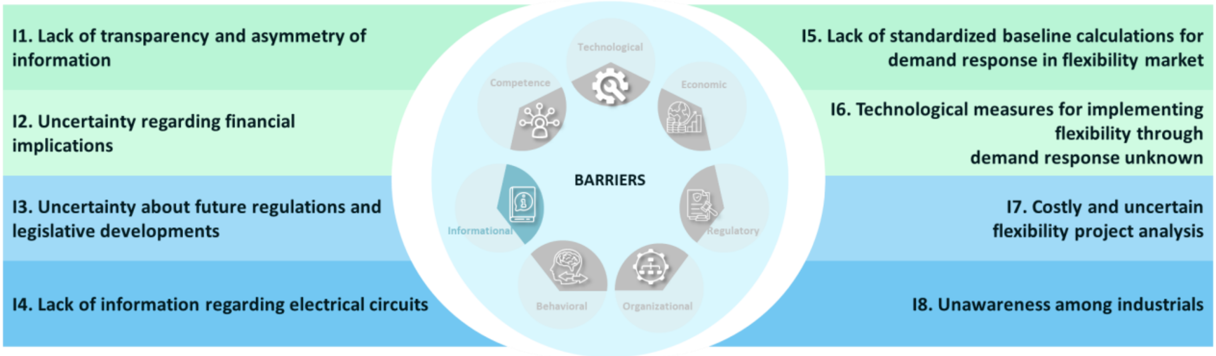

Figure 2-9: Overview of informational barriers

Table 2-6: Structured overview of informational barriers

Index	Barrier name	Barrier description	References
I1	Lack of transparency and asymmetry of information	Industrial actors often face a lack of access to timely and detailed information needed to make informed decisions about participation in flexibility markets. For example, aggregators typically have more insight into market prices, activation logic, and optimisation algorithms, while companies are left with limited understanding of how their flexibility is valued, how revenue is calculated, or why they are (not) dispatched. This information asymmetry can reduce trust and lead to suboptimal engagement. Moreover, flexibility market platforms or TSOs often do not publish real-time or forward-looking price signals, and offer limited visibility into activation patterns, which complicates independent bidding strategies. These transparency gaps create a disadvantage for industrial actors and may discourage active participation.	[38], [43], [53], [54], [69], [75], [80], [85], [90], [105]
I2	Uncertainty regarding financial implications	Uncertainty about future electricity prices, market revenues, and regulatory developments makes it challenging for companies to accurately assess the long-term profitability of flexibility projects, hindering investment decisions. Accurate forecasting of electricity prices and flexibility value is highly challenging due to market volatility, creating significant uncertainty and financial risks for companies planning to participate in flexibility markets.	[38], [39], [43], [44], [53], [54], [55], [68], [83], [93], [104], [119], [122], [85], [103], [109], [123]
I3	Uncertainty about future regulations and	Industrial actors face limited visibility into upcoming regulatory changes, including those affecting market design, eligibility criteria, remuneration mechanisms, or reporting obligations for flexibility. While regulatory	[38], [39], [43], [49], [54], [81], [95], [103],

	legislative developments	change is a normal part of the energy system evolution, companies often lack access to timely, clear, and consistent information about what changes are expected, on what timeline, and with what transitional provisions. This uncertainty complicates strategic planning and can delay investment in flexibility-enabling technologies, especially when future participation conditions (e.g. for aFRR, CRM, or local flexibility markets) are unclear or under revision.	[110], [112], [115]
I3.1	Unclear interpretation of legislation	Even when a regulatory framework exists, companies often struggle to interpret how it applies to their specific processes or assets, especially when dealing with flexibility mechanisms that involve technical, contractual, and regulatory dimensions. In some cases, this is due to genuinely ambiguous or novel legislation (e.g. around aggregation, CDS access, or metering requirements). In others, companies lack in-house legal expertise specific to energy regulation, forcing them to rely on external legal advisors, which increases costs and delays decisions.	[38]
I3.2	Uncertainty regarding allocation, roles, and responsibilities	Companies often face uncertainty regarding the allocation of roles and responsibilities among various market actors, complicating participation in flexibility programs and delaying project implementation.	[50], [60], [74], [85], [92], [94], [95]
I4	Lack of information regarding electrical circuits	Incomplete documentation of existing electrical infrastructure, particularly older installations, complicates assessment of feasibility for flexibility-enabling measures.	[62]
I4.1	No information regarding electrical circuit placement and types of cables	Incomplete knowledge about the location and specifications of existing electrical circuits hampers feasibility assessments of additional electrification required for enabling flexibility.	[62]
I4.2	Lack of electrical metering data	Older electrical circuits may lack suitable metering equipment, making it difficult to monitor their performance. This data is crucial for assessing the potential for flexibility and for electrifying processes.	[62]
I5	Lack of standardized baseline calculations for DR market	The absence of standardized and reliable methods to calculate baselines for demand-response measures leads to inaccuracies in compensation, reducing trust and attractiveness of DR participation.	[43], [52], [71], [81], [104], [105], [112], [115], [118]
I6	Unfamiliarity with technological solutions for DR	Companies often lack knowledge about available technical solutions for implementing demand-response, forcing them into costly external partnerships or substantial internal training efforts.	[38], [39], [45], [49]
I7	Evaluation of DR projects is complex, costly, and resource-intensive	Due to limited market transparency (I1) and the absence of standardised valuation methods (I2), evaluating the potential of demand response projects often requires customised, scenario-based analyses. These evaluations tend to be time-consuming, expensive, and uncertain, especially when assessing long-term economic benefits across multiple energy markets. As a result, many	[38], [42], [44], [45], [52], [53], [56], [57], [80], [81], [85], [89],

		companies hesitate to invest in DR, as the upfront analytical effort becomes a barrier in itself.	[105], [111], [122]
I8	Unawareness among industrials	Limited awareness among industrial companies regarding the potential, benefits, and practical implementation of demand-response significantly reduces participation and adoption of flexibility measures.	[124]

2.3.7 Competence-related barriers

Companies often lack internal expertise in DR implementation, particularly in energy markets and flexibility potential within their own operations. Insufficient knowledge about the production process' flexibility hinders the identification and exploitation of DR opportunities. Many firms also rely on external consultants due to the absence of in-house capabilities, increasing costs and dependency on third parties.

Figure 2-10 gives a graphical overview of the competence-related barriers to providing industrial flexibility. A detailed explanation for every barrier, including the relevant references is provided in Table 2-7. In the figure, only the main barriers are shown. Some barriers can be further divided into sub-barriers, which are discussed further down in the table.

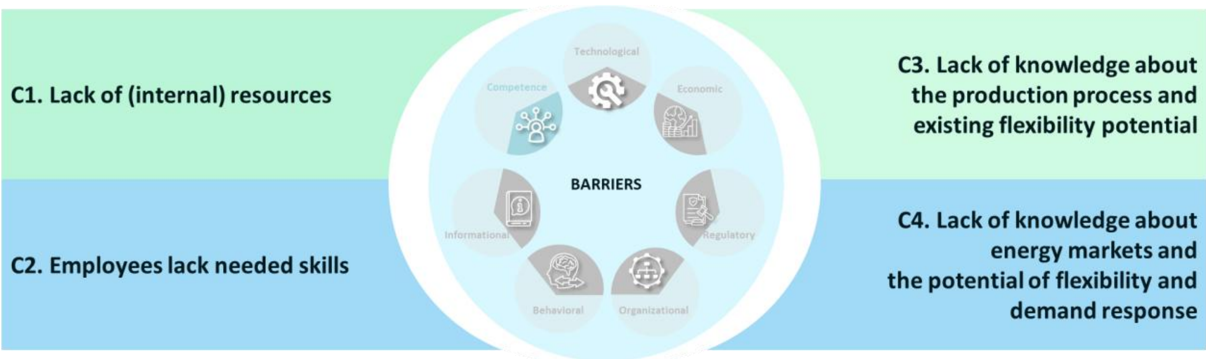

Figure 2-10: Overview of competence-related barriers

Table 2-7: Structured overview of competence-related barriers

Index	Barrier name	Barrier description	References
C1	Lack of internal resources	Companies frequently lack sufficient internal personnel, time, or budget to adequately engage with flexibility projects, leading to reliance on external partners or postponement of projects.	[38], [43], [44], [54]
C2	Employees lack needed skills	Employees often lack the necessary technical and operational expertise required to effectively manage flexibility measures, resulting in reliance on external experts or additional internal training.	[38], [39], [42], [43], [44], [52], [53], [54], [77], [78], [86], [110], [121]
C3	Lack of knowledge about the production process and existing flexibility potential	Companies often lack detailed knowledge of their own production processes and the associated flexibility potential. Furthermore, companies frequently prioritize production data over energy-related data, limiting accurate assessment and implementation of flexibility measures.	[38], [44], [52], [81], [86], [105]

Index	Barrier name	Barrier description	References
C4	Lack of knowledge about energy markets and the potentials of DR	Many companies lack sufficient in-house knowledge of how energy markets function, how demand response is valued across different market layers (e.g. balancing, capacity, tariffs), and how regulatory frameworks shape participation conditions. Even when external information is available (see I8), companies may lack the capacity to interpret, apply, or act on it, for example, due to unfamiliarity with market rules, role definitions, or contractual mechanisms. This competency gap prevents companies from identifying flexibility potential or assessing relevant business models.	[38], [43], [48], [53], [77], [80], [81], [82], [91], [93], [96], [105], [112], [115], [119], [121]

2.3.8 Overarching insights

The analysis of barriers to industrial flexibility highlights several overarching insights that help to understand where the key challenges lie. The assessment of barriers reveals that economic and technological barriers dominate the academic discourse, as seen in Figure 2-11. The figure summarises our literature scan by counting how often each barrier category is mentioned across the reviewed references. The bars reflect frequency of appearance, not the weight or severity of barriers.

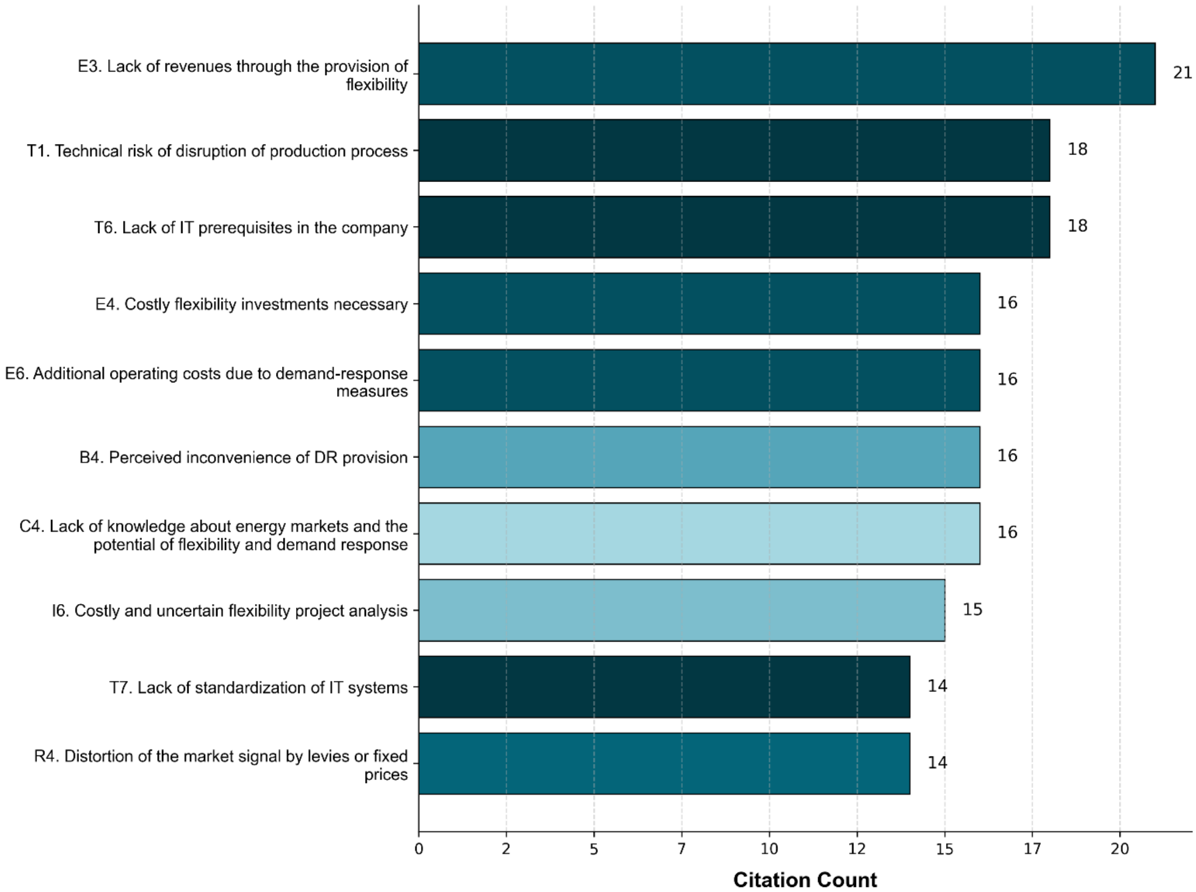

Figure 2-11: Ten most cited barriers overall. Each barrier category is indicated by a unique colour.

The economic barriers primarily revolve around the lack of sufficient revenues to justify industrial flexibility participation (E3), the high investment costs required to enable flexibility (E4), and additional operating costs associated with demand-response participation (E6). These findings underscore the fundamental challenge that many companies do not see flexibility as financially attractive under current market conditions. Either the revenue streams are insufficient, or they are too uncertain when weighed against the associated costs, making flexibility a less viable option for many industrial players.

On the technological side, the risk of disruption to production processes (T1) emerges as a significant concern, highlighting the reluctance of industrial players to interfere with core operational workflows. Additionally, the lack of IT prerequisites (T6) and the absence of standardization in IT systems (T7) indicate that the digital backbone needed to enable seamless flexibility participation is often underdeveloped, requiring substantial investments and effort.

The overview in Figure 2-11 is further completed with the behavioural barrier of perceived inconvenience of DR provision (B4), the lack of specific knowledge about energy markets (C4) and the lack of information manifesting as costly and uncertain flexibility project analysis (I6). Finally, there is one regulatory barrier, which is the distortion of market signals (R4).

2.4 Deep-dive into company and sector barriers

While the previous section was a more general discussion of barriers, the current section focusses on the specific barriers to industrial flexibility faced by different industrial sectors in Belgium. The content of this section is based on a collection of interactions with the GALILEO industrial partners where they were asked about the specific barriers they faced, as a company and as a specific industrial sector, in the provision of industrial flexibility. The section starts by providing a general overview of the barriers faced by all the companies and then deep-dives into the separate companies and sectors. After the analysis at company and sector level, we extract conclusions related to barrier relevance and prioritization.

While literature provides a strong foundation for understanding key barriers, practical experiences from company interactions reveal additional critical factors. Notably, grid-related constraints were widely emphasized by companies but are largely underrepresented in academic sources. This discrepancy suggests that research has primarily focused on market and operational aspects while underestimating the infrastructural limitations companies face.

In practice, companies highlighted technological barriers such as existing grid congestion and difficulties with grid expansion. These issues create significant constraints on flexibility participation, as companies may be physically unable to adjust their electricity demand even if they are otherwise willing. Additionally, regulatory uncertainties surrounding flexible grid connections add another layer of hesitation, as unclear rules on how grid operators will handle such arrangements prevent companies from making informed decisions. Informational gaps further compound these problems, as companies frequently cited a lack of metering data and inadequate knowledge of existing electrical circuits as major obstacles to understanding and optimizing their flexibility potential.

2.4.1 General overview of barriers

Figure 2-12 provides a general overview of the number of times a specific barrier was cited by a specific company/sector.

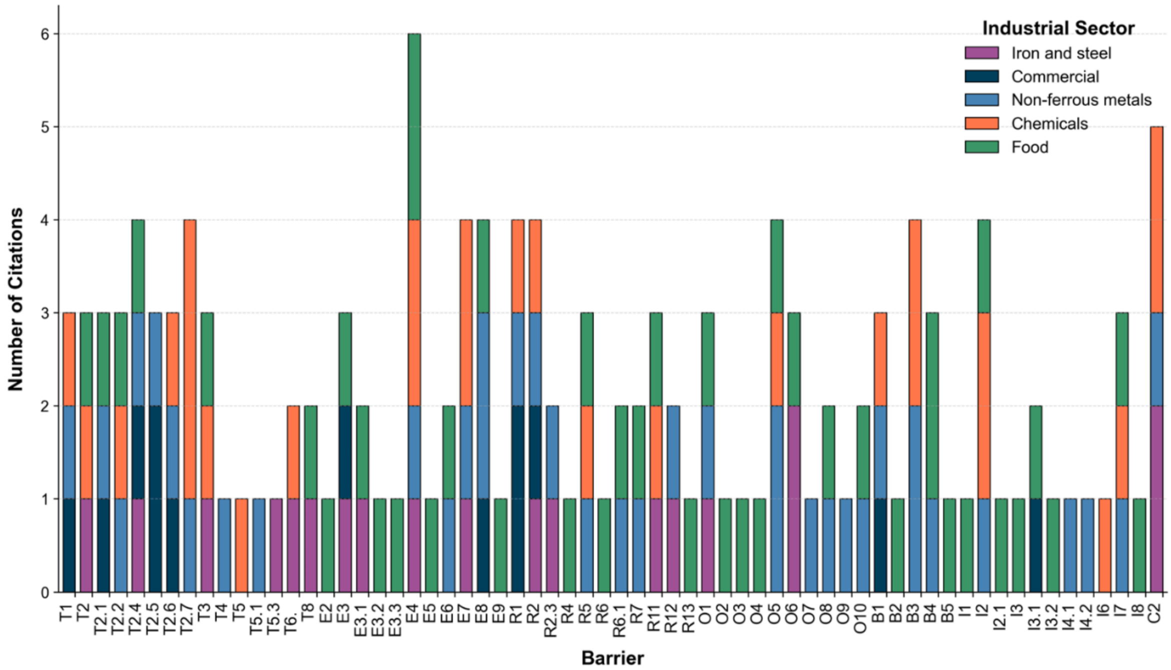

Figure 2-12: Number of times specific barriers were cited by the different companies, extrapolated to sector level

Viewing the cited barriers by the GALILEO companies, there is a strong correlation with the barriers reported in the literature. Yet, differences exist in how barriers are perceived in practice. The literature tends to emphasize macro-level issues of market design, regulation and infrastructure, whereas companies highlight practical, financial and operational hurdles they encounter in implementation.

Overlap is clear for several high-salience items. Economic barriers that dominate in the literature, such as high investment needs and uncertain or insufficient returns (E4, E3), also appear as critical in company input. Likewise, key regulatory barriers recur on both sides, notably the complexity of the framework and restrictions that limit access in practice (R1, R2).

A difference in emphasis is equally visible. Literature-based counts focus more on systemic aspects, while company reports foreground plant- and firm-level issues, for example limited internal skills and misaligned performance metrics (C2, O5). Conversely, some items that receive substantial attention in publications do not emerge as the most pressing in practice. A case in point is C4 (knowledge of energy markets and DR potentials), which is widely discussed academically, but is often overshadowed on the shop floor by technical feasibility concerns captured under the technological cluster (for example process constraints and prerequisites in T2.1 to T2.7 and T6).

The sector colour distribution in Figure 2-12 shows distinct profiles. The chemicals sector (orange) spans the broadest range of barriers; although technological barriers slightly dominate, all six other categories are represented. At the other end of the spectrum, the commercial sector (dark blue) is comparatively sparse and dominated by technological barriers that limit the availability of flexibility. Among the remaining sectors, the food sector reports strong economic barriers with notable organisational barriers; the non-ferrous metals sector is led by informational and organisational barriers; and the iron and steel sector is balanced across technological, economic, and regulatory barriers. These patterns indicate that perceived bottlenecks are sector specific.

Finally, while some barriers are clearly specific to one company or sector, many are shared across sectors. Section 2.4.2. will detail these commonalities and differences at sector level.

2.4.2 Sectoral overview of barriers

In this section, we delve deeper into the barriers faced by different companies and sectors to identify sector-specific insights. The identified barriers stem from interactions with the various GALILEO partner companies and are of a highly practical nature, reflecting real challenges these companies have encountered. During discussions, it became evident that some barriers are interlinked across different categories, meaning that certain practical obstacles can simultaneously have technological and economic dimensions. Therefore, each practical barrier has been assigned a sectoral index (*italicized in brackets*), while always being linked (in brackets) to one or more general barriers identified in the previous section.

For each sector, a graphical overview of the barriers is provided by means of an Ishikawa or fishbone diagram. This is a causal diagram that shows the potential cause of a specific event, in this case, the causes or barriers to industrial flexibility.

Finally, given the practical foundation of this sectoral barrier analysis—rooted in real company discussions—we also provide an interpretation of how these barriers can be aggregated to a broader level. We assess to what extent these insights can be extrapolated to the entire sector and highlight key considerations when doing so.

2.4.2.1 Chemical sector

Figure 2-13 presents the fishbone diagram for the barriers to industrial flexibility for the chemical sector.

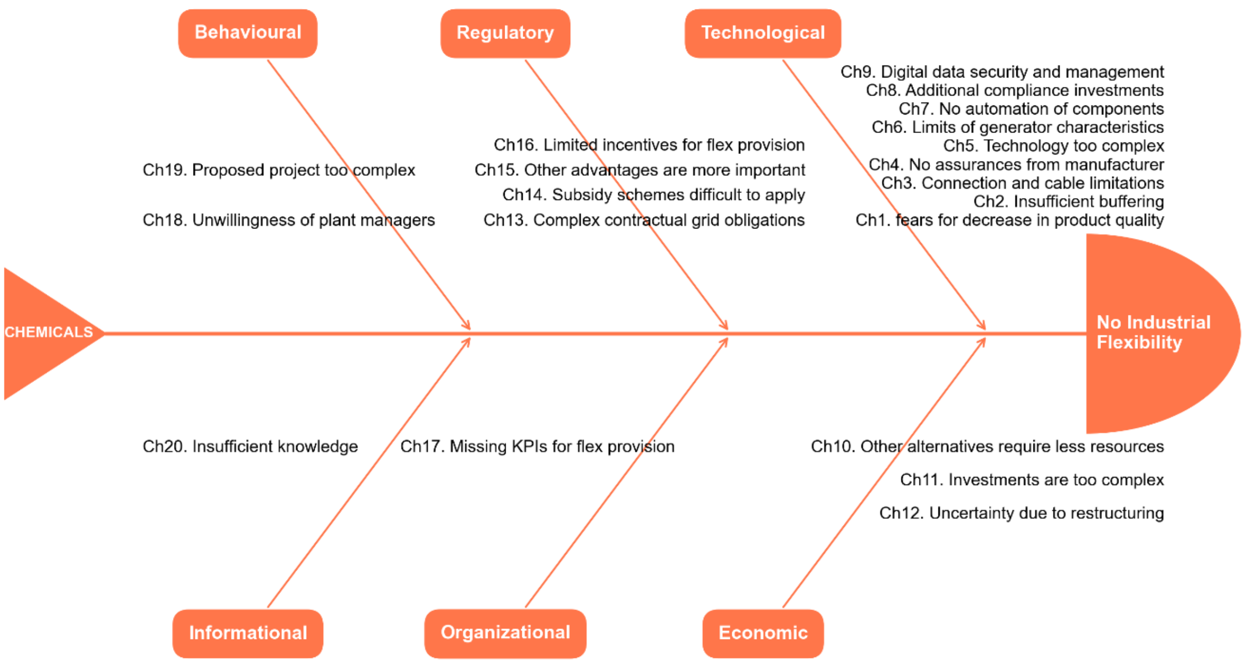

Figure 2-13: Fishbone diagram of barriers to industrial flexibility for the chemical sector

From the figure it is clear that most barriers in the chemical sector are of a technological nature. Regulatory barriers are the second-most present. The barriers are described in more detail below.

The first barrier (*Ch1*) relates to **fears from the production plant for a decrease in product quality by applying flexibility,** by e.g., a decrease in product quality, equipment failure etc.

This is particularly critical when process steering is involved, as even small deviations can disrupt chemical reactions and product consistency. In the chemical industry, these risks not only impact production output but also result in raw material losses. For catalytic processes, which account for approximately 90% of all commercially produced chemicals in general, flexible operation might deactivate the catalyst, leading to process failure. Similarly, in exothermic reactions, flexibility measures can disrupt heat balance and equipment design considerations, causing inefficient heat transfer and process instability. An example of this is iron crystallization in industrial chemical processes that involve iron-containing compounds. If temperature control fluctuates due to flexible operation, undesirable iron precipitates can form, leading to clogging in pipelines, contamination of end products, and reduced process efficiency. Moreover, aging equipment can limit the extent of flexibility, as older systems are often less adaptable to rapid changes in operating conditions. Additionally, HAZOP (Hazard and Operability) studies often do not account for the novelty of flexible operations, meaning potential risks may not be fully identified or mitigated before implementation[1].

The second barrier (*Ch2*) has to do with **insufficient buffering being in place** as the production is based on the demand for the product. The planning needs to take into account how much of the product is stored and how fast it can be used and sold (T2.2). For example, in fertilizer production, products like potassium sulfate (SOP) and ammonium sulfate are bulk materials that require large storage silos. However, these silos are often already operating at full capacity, leaving little room for production adjustments. Increasing storage capacity would require significant capital investment and available land space, which is not always feasible due to site constraints.

Then there are barriers caused by **electrical grid connection and cable limitations** due to the quality and the age of the cables which do not allow for flexibility (*Ch3*). As the production plant did not want to replace the cable, the cost for replacement would be placed under the specific flexibility project, which killed the project as the payback period became too long (T2.6, E4, E7).

The next barrier (*Ch4*) is related to specific technology required for the flexibility project and for which the manufacturer **cannot provide the assurances for the project needs** (T2.7). A concrete example is the use of a hydrogen engine, where the technology provider could not guarantee that the engine would run beyond 2000 load hours. However, for the business case to be viable, the engine needed to operate for at least 4000 load hours within a three-year payback period. This short payback period was essential because the site anticipated another project within three years, meaning a longer investment horizon was not feasible. The uncertainty surrounding the operational lifespan of the engine made it too risky to invest, ultimately preventing the flexibility project from moving forward.

Related to that, the **technology can be too complex** (*Ch5*). This can be either the process technology on which the flexibility would need to be applied to, or the ancillary technology needed to provide the flexibility (T2.7). Referring again to the hydrogen engine project, even for the technology provider, the application of the engine within the chemical processes and operations was highly complex, leading to significant uncertainties that could not be fully calibrated. Because these factors could not be reliably modelled, it became nearly impossible to provide performance guarantees, further undermining the feasibility of the investment.

Another specific barrier related to process complexity (*Ch6*) is that there is a **need to stay within the limits of the generator** to take into account reactive power to avoid equipment failure (T2.7). This conflicts with the potential needs of the flexibility business case. In industrial environments, generators play a critical role in power stability, ensuring that voltage levels and

[1] HAZOP studies check everything that could go wrong and state which redundancies need to be in place to avoid these situations. If the process has the option to be managed in a flexible way, this should be taken into account during HAZOP studies. Hence, if flexibility was not taken into account for the approved HAZOP study, the study needs to be adapted to include everything that could go wrong when applying flexibility, which would require a lot of time and budget.

reactive power remain within acceptable limits. However, implementing flexibility measures—such as ramping production up or down, switching between energy vectors, or adjusting power loads in response to price signals—can introduce significant fluctuations in reactive power demand. If these fluctuations exceed the design tolerances of the generator or the site's power infrastructure, they can lead to voltage instability, inefficient power factor correction, and even equipment malfunctions or failures.

The next technological barrier (*Ch7*) is the **lack of automated controls** to be able to participate in flexibility markets (T6). Many process operations still occur partially manually or are reliant on dated control systems, making real-time adjustments difficult or impossible without significant investments in automation. For example, in chemical production, many pumps, valves, and heat exchangers are controlled through local setpoints, requiring manual intervention to adjust operations.

This challenge extends to **compliance with grid regulations** (Ch8), where participation in ancillary services or day-ahead markets requires upgraded control and dispatch systems to ensure accurate and reliable flexibility provision (T5, E4, C4). For instance, if certain sites of the chemical company wanted to provide balancing services (aFRR or mFRR), they would need automated, real-time control over their large-scale industrial assets. However, current infrastructure often lacks the necessary integration with grid operators, meaning that flexibility activation cannot happen within required response times (e.g., within seconds for frequency control). Moreover, upgrading these systems requires high upfront investments, making participation economically challenging.

Additionally, **digital security and data management (Ch9)** present further barriers, necessitating the involvement of both IT and OT departments (T5.3). In industrial settings like chemical production plants, the risk of cyber threats is significant, as any unauthorized control over process equipment could lead to safety hazards, environmental risks, or production shutdowns. While IT teams focus on securing data networks, firewalls, and external connections, OT departments handle the physical process risks associated with external flexibility signals.

The first economic barrier (*Ch10*) has to do with the fact the **other alternatives** than the one that can provide flexibility are **less complex, safer** to use and require **less resources.** A clear example of this is the choice between an H_2 engine, which can offer greater operational flexibility, and an H_2 boiler, which is simpler to implement but primarily follows heat demand rather than market-driven flexibility incentives (E2).

The next economic barrier (*Ch11*) concerns the **high costs and complexity** of investing in new **electricity infrastructure**, which is often not only required for flexibility provision, but also a prerequisite for electrifying industrial demand (E4). When transitioning from fossil-fuel-based heating to electrical alternatives, such as e-boilers, existing grid connections and cabling may lack the necessary capacity to handle the increased electrical load, leading to significant upgrade costs. A concrete example of this issue occurred when a site planned to install an e-boiler to replace a fossil-fuel-based heating system. However, the existing electrical cables were outdated and could not support the additional power demand. Since the site management chose not to fund a general cable upgrade, the cost burden of replacing the cables was placed entirely on the e-boiler project. This dramatically increased the project's investment requirements, making the payback period too long and ultimately causing the project to be cancelled.

Moreover**, increased uncertainty due to production plant restructuring** (*Ch12*) can also be a barrier. Variation in activities and discontinuity of production lines make that it becomes difficult to plan for flexibility projects which usually have a longer payback period (E7, I2).

Several regulatory barriers were identified, particularly concerning the practical setup of grid connections, where a company relies on another entity for access, leading to **complex contractual obligations** and a **need for coordination (Ch13)** with the closed distribution system (CDS) owner (R1). A major challenge arises when industrial sites are connected behind the meter of another company, meaning they do not have a full, independent European Artice Number (EAN) and lack direct grid access. This setup restricts market access and flexibility participation, as all transactions and regulatory compliance must be handled through the main grid-connected company. This dependency complicates several aspects of energy management. Price definitions become more complex, as cost allocation between the main grid-connected company and the behind-the-meter entity lacks transparency. Access to flexibility products is also limited, since the site cannot independently bid in demand response or ancillary service markets, reducing its ability to monetize flexibility. Furthermore, contracting becomes more cumbersome, as any flexibility participation, energy procurement agreements, or PPAs (Power Purchase Agreements) must be arranged through the main grid-connected company, adding administrative complexity. This also affects energy procurement strategies, as the behind-the-meter site has limited influence over sourcing decisions, making it harder to optimize energy costs based on its own operational needs.

When it comes to subsidies, **various schemes contain clauses that make them difficult to apply** (*Ch14*). For instance, some recently introduced subsidy schemes, like TRACKS Klimaatsprong, have a long running period (+10 years), which is too long for the industry and increase uncertainty, e.g., in the case of plant closure the received subsidy grant will need to be repaid (R2, R11). Moreover, there is a **lack of sufficient incentives for flexibility provision** (*Ch16*), particularly in the form of state support schemes tailored for industrial environments (R11). While policy frameworks encourage industrial decarbonization, they often focus on energy efficiency measures and renewable integration rather than demand-side flexibility. One illustrative example of this is the upcoming solar panel obligation in Flanders, which requires that, by June 30, 2025, all buildings with an electricity consumption exceeding 1 GWh per year must have solar panels installed. This obligation applies to owners, leaseholders, and usufructuaries of such buildings, ensuring a broad implementation of self-generation capacity. Although such measures are essential for industrial decarbonization, they also mean that available financial resources are first allocated to these compliance-driven investments, rather than to flexibility-enhancing measures. Industrial companies must prioritize capital expenditures for mandatory solar installations, leaving less budgetary room for investments in technologies that improve flexibility.

Additionally, companies may prioritise **other operation strategies**, like grid-fee optimisation (*Ch15*), i.e., scheduling consumption to maintain favourable tariff bands or lower capacity charges, which can outweigh the benefits of flexibility (R5). Large industrial consumers often benefit from preferential grid tariff structures based on their steady, predictable consumption profiles. Engaging in flexibility measures, which introduce load variations, may jeopardize these advantageous tariff conditions, making flexibility less attractive from a cost perspective. As a result, companies may prioritize tariff stability over the uncertain financial returns of flexibility.

A key organizational barrier to industrial flexibility is that **it is not structurally integrated into the production environment** (*Ch17*). At the company level, flexibility is not recognized as a core business function, and as a result, it is **not reflected in Key Performance Indicators** (KPIs) (O5). This means that energy flexibility is not a formal target for plant managers or production teams, limiting their incentive to engage in demand-side flexibility initiatives. In industrial settings, production efficiency, stability, and cost control are the dominant priorities. Companies typically measure success based on throughput, uptime, and quality assurance, whereas participation in flexibility markets is not incorporated into performance evaluations. This creates a fundamental misalignment between energy management and production operations. Even if energy managers see the financial and operational benefits of flexibility, they struggle to convince plant managers to adopt such measures, as they do not directly contribute to the company's core performance indicators. Moreover, this KPI structure reinforces **resistance to flexibility** (*Ch18*), as plant managers prioritize production targets over energy optimization. Even where KPIs are neutral or supportive, managers may oppose flexibility because they anticipate reliability risks, added operational complexity or loss of control. Reported drivers include a strong reliability culture, prior negative experiences with automation, low perceived competence with DR tools and an accountability asymmetry in which production losses are highly visible while flexibility revenues are uncertain. This typically manifests as a preference for steady-state operation and reluctance toward near-real-time interventions (B1, B3).

It is not only the absence of flexibility in KPIs that leads to resistance from plant managers, but also the fact that **flexibility projects are often perceived as too complex** to implement for plant managers (*Ch19*). Many of these initiatives require technical modifications, integration with automation systems, or changes in operational planning, which add an extra layer of complexity to already demanding production environments. Plant managers, whose primary focus is on maintaining stable operations, meeting production targets, and minimizing downtime, may see flexibility projects as an overwhelming amount of work with unpredictable consequences (B3, C2).

This perceived complexity is further exacerbated by informational barriers (*Ch20*), where there is **insufficient knowledge and understanding of the benefits and risks** of providing flexibility (I2, I6, I7, C2). Many industrial sites lack clear data and insight into how flexibility measures impact energy costs, operational efficiency, and financial returns. For instance, a decision to provide flexibility at a certain quarter-hour of the day might seem beneficial in the moment, but could have hidden long-term cost implications. If that decision increases peak capacity demand, it could trigger higher contracted capacity charges, which must be paid for the next 12 months, outweighing any short-term flexibility revenues. The challenge lies in the lack of knowledge and understanding to accurately assess whether the immediate benefits of flexibility outweigh the potential long-term costs.

Extrapolation from company to sector level

The barrier pattern observed at the case plant can reasonably be extrapolated to the chemical sector because it reflects structural features of chemical production rather than site-specific peculiarities. Chemical sites principally operate in baseload profiles for reasons of cost competitiveness, yield optimisation, safety and technical necessity, which narrows the feasible window for demand-side flexibility and makes it highly site specific. This sector reality cautions against overstating flexibility potential and frames it as conditional on process and site constraints. The extrapolation is further supported by governance and incentive structures that are typical for the sector. Flexibility is rarely embedded as a production objective and is often absent from key performance indicators for plant and line management, while reliability, throughput, and quality remain the dominant priorities. These features create a consistent alignment between what is technologically feasible on the floor and what is incentivised in day-to-day operations, which in turn amplifies informational and competence gaps around the evaluation of demand-response options.

Technical limitations that restrict modulation are inherent to the way processes are linked and controlled. Cascading interdependencies across units mean that the flexibility limit of one unit can cap the flexibility of others or of the entire site, while ramp-rate limits, safe operating envelopes and start–stop penalties constrain dynamic operation. Storage headroom also bounds upward modulation, since additional production must be absorbed in intermediates or finished products under both physical and legal limits. Chlor-alkali operations are a documented example where legal caps on storing caustic soda, chlorine and hydrogen effectively bound how much energy can be absorbed. These considerations explain why flexibility measures must be engineered and governed by on-site expertise, and why many chemical plants require significant enabling investments in metering, control and integration before participating in faster products is technically feasible.

Greater operational variability can also depress process efficiency and alter emission loads. Where excursions fall outside normal operating ranges, they may need to be treated as other-than-normal operating conditions under the Industrial Emissions Directive, which implies the definition of appropriate controls. This reinforces the earlier finding that flexibility and efficiency objectives can be in tension at the plant level and that permitting considerations form part of the feasibility assessment.

Finally, alternatives to direct load modulation are relevant for chemicals. On-site generation and storage can provide system services while preserving steady production profiles, but both face substantial upfront costs and therefore benefit from appropriately designed support in early deployment phases. Where storage or additional production capacity is used to absorb oversupply, the same legal and physical storage constraints that limit demand response also apply.

2.4.2.2 Commercial sector

Figure 2-14 shows the barriers to flexibility faced by the commercial sector, in form of a fishbone diagram. Please note that the commercial sector in GALILEO relates to collocation data centres and we are specifically addressing barriers these companies face.

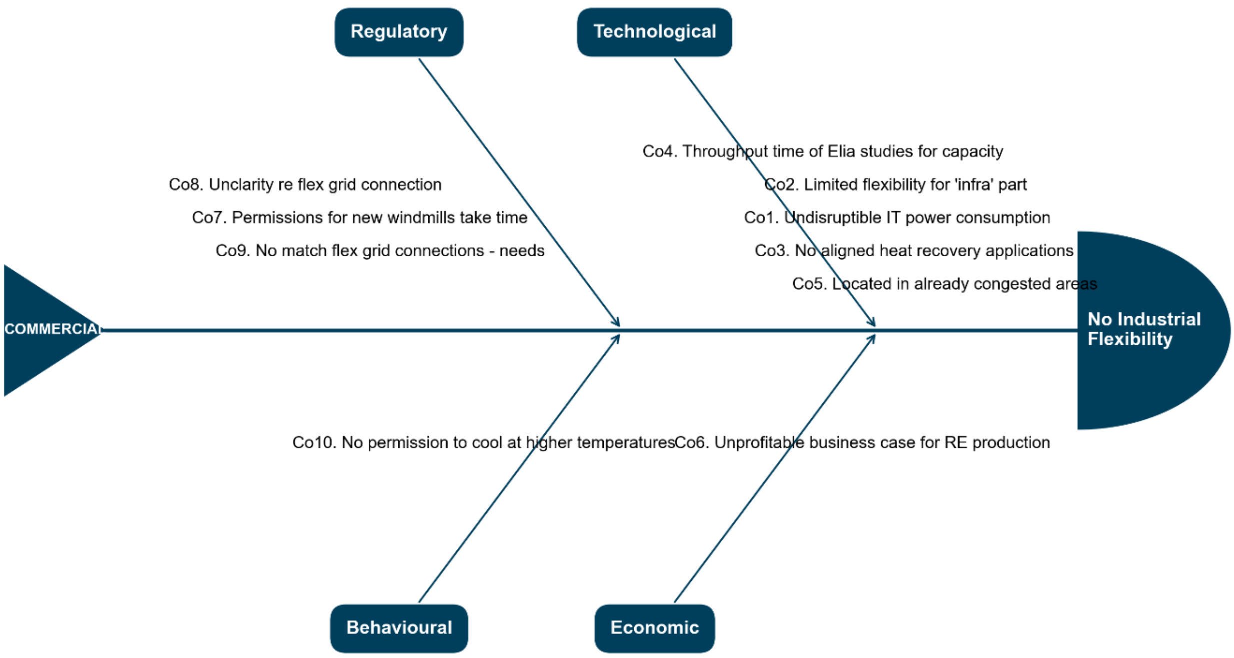

Figure 2-14: Fishbone diagram of barriers to industrial flexibility for the commercial sector

The first technological barrier has to do with the **strict conditions that need to be met for IT power consumption** (*Co1*). The power consumption in data centres is divided into two parts: IT power consumption and infrastructure power consumption. IT power consumption powers all the IT infrastructure and makes sure, for instance, that all data transfers can be executed. Infrastructure consumption entails every other use of power needed to support the IT part and is mostly related to cooling. IT power consumption is fixed and cannot be varied nor disrupted as the risks associated with losing access to data are too high. The IT equipment therefore needs to be live 99.982% of the time (T1, E8). Flexible power consumption is partly possible in the infrastructure part, for instance using buffer barrels, but also there **the power consumption has limited flexibility** (*Co2*). Data centres do have uninterruptible power supply (UPS) systems which contain generators and batteries. However, to not impact the continuity of data centre services, these cannot be directly connected to the grid and need to remain separate (T2.1).

Additionally, **client resistance to increasing cooling temperatures** (*Co10*) presents a behavioral barrier in colocation data centers[2] which further limits the available flexibility. While modern IT equipment is designed to withstand higher operating temperatures, some clients insist on maintaining lower cooling setpoints, often out of habit or risk perception rather than technical necessity. Increasing cooling temperatures would significantly reduce energy consumption and enhance operational flexibility (B1).

For heat recovery to be feasible (*Co3*), **suitable offtakers must be available** in the vicinity of the data centre or a district-heating connection must exist. These offtakers need to be able to use the residual heat at the available temperature level and with a demand profile that matches the data centre's supply. In practice, this spatial and thermal matching is often absent, and developing the required distribution assets is not core business for data centres. As a result, data centres are generally reluctant to originate and coordinate such projects themselves, and a third party (e.g. a district-heating operator or ESCO) is needed to lead development and contracting (T2.4).

Another barrier has to do with grid connections and the **long throughput of Elia studies for additional grid capacity** (*Co4*). Moreover, the fact that request for additional grid capacity are treated in order of reception, independently of who own the plot, means that investment firms lock grid capacity to sell it afterwards, making it difficult for the data centre industry to move forward (T2.5). Certainly, as **data centres** must be close to customers due to latency requirements, they must be **located in areas where the grid is often already congested** (*Co5*). This makes it difficult to add load to an existing grid connection or acquire new connection capacity, which is often needed to provide flexibility (T2.5, T2.6).

As a solution to grid congestion and to accelerate grid connection timelines, non-firm grid connection agreements are being introduced. While these flexible grid connections may provide a viable option for certain industries and assets, they pose significant challenges for data centres due to the **mismatch between flexible grid access and the sector's strict uptime requirements** (*Co9*). In some cases, it is no longer possible to obtain a fixed-capacity grid connection, leaving data centres with only flexible grid connection options. However, this is not a viable solution, as data centres require continuous power availability at 99.982% uptime. Any downtime in IT systems could lead to severe economic consequences, including disruptions in banking transactions, railway communication systems, and other critical infrastructure (R2). Adding to this challenge is the **lack of clarity regarding the content and implications of flexible grid connection agreements**, particularly for new data centre expansions (Co8). The term "flexible" remains ambiguous, and there is uncertainty about how flexibility requirements would be enforced in practice. A critical distinction must be made between sporadic downtime events spread across the year (e.g., outages totalling two weeks over 12 months) versus back-to-back interruptions that could severely impact redundancy planning and backup investments (R1, I3.1). Without clear contractual definitions and regulatory guidance, data centres face major investment uncertainties, as they cannot determine the level of resilience and redundancy needed to mitigate potential disruptions.

An economic barrier is that the **business case for additional own renewable energy (RE) sources is not always profitable** (*Co6*). The profitability of new RE capacity depends critically on the site's self-consumption ratio, which in turn depends on demand-side flexibility. A weak RE business case indirectly suppresses flexibility activation by removing both the driver (cheap on-site energy to align with) and the enablers (assets and systems needed to modulate demand). If loads cannot be shifted to RE production hours or buffered via storage, surplus

[2] A colocation data centre is a facility that rents out rack space to third parties for their servers or other network equipment. Hence, they offer services to businesses that may not have the resources needed to maintain their own data centre but still want to enjoy all the benefits.

PV or wind must be exported at low or uncertain remuneration and may attract additional grid charges, depressing the business case (E3).

Another significant challenge is the **lengthy permitting process for energy investments** (*Co7*). Obtaining the necessary permits for windmill construction often takes more than 10 years, creating long lead times and regulatory uncertainty (R1). This extended waiting period significantly increases investment risks, as market conditions, policy frameworks, and energy prices may change unpredictably before the project becomes operational. Such delays hinder the ability of data centers to secure long-term renewable energy supply, impacting their sustainability targets and energy procurement strategies. The same uncertainty also delays complementary on-site investments to increase self-consumption, such as batteries, thermal storage, and smart controls, which could subsequently be leveraged to provide demand-side flexibility. Postponing these investments limits near-term flexibility potential and sustains exposure to price and grid-charge volatility.

Extrapolation from company to sector level

The barrier pattern identified in the case study translates well to commercial data centres as a whole because it reflects structural features of the sector rather than site-specific circumstances. Commercial data centres operate with very high availability requirements, a strict separation between IT load and facility load, and limited tolerance for operational variability. Under these conditions, IT power is effectively firm, which confines most demand-side flexibility to the facility domain, primarily cooling optimisation and small thermal buffers (Co1, Co2, T1). Although UPS systems and back-up generators are ubiquitous, many sites are not configured or permitted to run these assets grid-interactively, which constrains participation in short-notice products (T2.1). Location further reinforces this profile: to meet latency requirements, facilities cluster in urban or peri-urban areas where distribution networks are often capacity-constrained, so connection upgrades face long queues and additional capacity is difficult to secure (Co4, Co5, T2.5, T2.6). Non-firm connection agreements seldom resolve this because flexible access conditions are hard to reconcile with five-nines uptime, and current templates leave enforcement and coordination parameters insufficiently defined, which raises investment uncertainty for expansions (Co8, Co9, R1, R2, I3.1).

While these barriers are common across commercial data centres, their expression differs by business model.

- Collocation facilities (multi-tenant). Workload timing and placement are controlled by tenants, so flexibility remains predominantly facility-side and narrow. Multi-tenant SLAs and governance limit changes to cooling setpoints, grid-interactive use of UPS, and coordination for heat valorisation. Urban siting and distribution-level constraints make additional capacity difficult to obtain, and non-firm connection agreements are generally incompatible with the required service availability.
- Hyperscale campuses (single-tenant). Operators retain control over non-urgent workload timing and, within latency and data-residency constraints, limited geographic placement. This enables a measured degree of IT-layer flexibility, for example time-shifting analytics, backups, or training jobs to periods of lower grid stress or higher renewable availability, and shaping non-critical compute intensity through orchestration policies.. As a result, the feasible flexibility window is typically broader than in collocation, although still bounded by strict availability requirements and local grid conditions.

2.4.2.3 Food sector

Figure 2-15 shows the fishbone diagram for barriers to industrial flexibility for the food sector. The barriers in the figure are summarized but individually explained in more detail below.

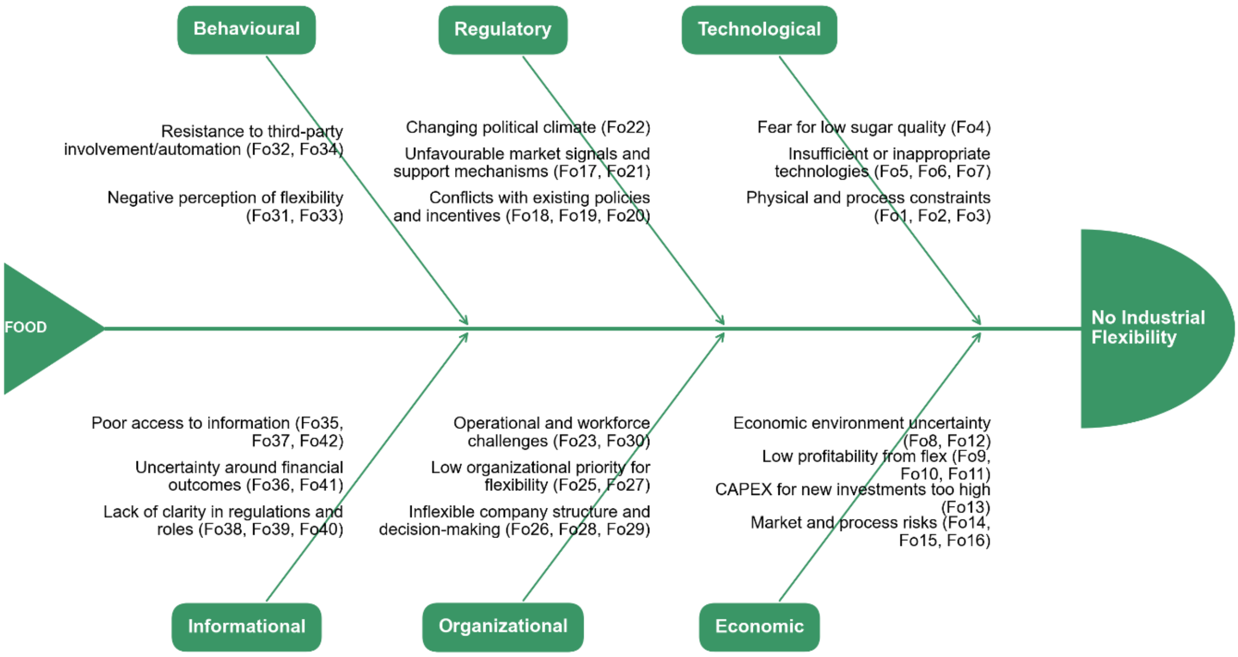

Figure 2-15: Fishbone diagram of summarized barriers to industrial flexibility for the food sector

A major technological constraint is the **infeasibility of reducing the peak load of the production process**, as the sugar beet processing operates at maximum capacity throughout the campaign period (*Fo1*). Unlike some industries where production can be ramped up or down, sugar refining is a continuous and time-sensitive process, meaning that load reductions are not an option without significantly affecting output (T2.1). For example, sugar beets are harvested in Q4, and almost immediately after being extracted from the fields, they must be processed. The harvest and processing period runs from September to January and during this period, the plant operates 24/7. Beyond this timeframe, the beets either remain too raw or degrade in quality. This biological constraint means that the refinery has no flexibility in shifting production schedules to match market signals. The remaining part of the year (February–August) sees no production activity, there is no opportunity for load shifting.

The **seasonal nature of the beet campaign** creates an additional barrier (*Fo7*). Sugar production is highly concentrated from September to January, which is when the refinery has the process running. However, for flexibility to be valuable, it must align with market demand for flexibility services (T8). If the highest flexibility needs in the energy system do not coincide with the beet campaign period, the financial incentives for implementing flexibility are diminished. This seasonal characteristic of the production process and the potential misalignment between industrial flexibility potential and market demand makes it difficult to establish recurring flexibility revenues, further discouraging investment in long-term flexibility solutions.

Furthermore, **storage constraints** impose additional flexibility limitations *(Fo2*). Sugar beets have a very limited storage life, as prolonged storage leads to sugar degradation, making it impossible to shift production schedules to respond to electricity market signals (T2.2). This is a fundamental barrier, as it prevents the refinery from decoupling the harvesting from the raw material processing.

Another technological barrier is the **absence of external demand for residual waste heat** (*Fo3*). While some industrial sectors can optimize flexibility by using or selling waste heat, this option is not viable for the Sugar refinery. Stakeholders have shown no interest in utilizing waste heat, and it is perceived as if Belgium currently lacks a political framework to incentivize sustainable district heating (T2.4). Additionally, local governments are reluctant to invest in waste heat infrastructure, as the benefits would materialize only after their term in office, making it politically unattractive.

Providing flexibility in sugar refining would require start/stop cycles in production, which could **compromise sugar quality** (*Fo4*). Process interruptions can alter the crystallization process, leading to inconsistencies in sugar purity and texture, ultimately affecting final product quality. Additionally, more frequent stops and restarts would increase the need for sugar reprocessing, leading to higher operational costs and reduced efficiency (T3, E6). This trade-off between maintaining product quality and integrating flexibility measures makes flexibility less attractive for sugar refineries, where process stability is a key priority.

Another key barrier is related to **IT security and data exchange requirements** (*Fo5*). Strict cybersecurity protocols prevent seamless data sharing, which is crucial for participating in flexibility markets (T5.3). If the data exchange occurs outside of the company's internal network, it poses fewer challenges. However, if data exchange is required within the network, it must comply with stringent internal security policies, significantly complicating real-time participation in demand response programs.

Another technological barrier is the **absence of appropriate technology to control flexibility-providing measures** (*Fo6*). While the sugar refinery operates with multiple industrial control tools, these systems are not interconnected under a single overarching platform capable of steering flexibility across all processes (T6.1). Developing such a centralized energy management system would require significant investments, making it difficult to justify from a business case perspective

A major economic barrier is that **investing in energy efficiency is far more cost-effective than pursuing flexibility** (*Fo8*). Since sugar beet processing is highly energy-intensive, particularly in the evaporation phase, even a slight increase in energy efficiency leads to greater cost savings than potential earnings from flexibility (E2). The industry primarily relies on evaporation for sugar concentration, and since energy efficiency measures directly reduce energy demand, they provide immediate and predictable financial benefits. By contrast, flexibility revenues are uncertain and depend on volatile market conditions. As a result, the sugar refinery prioritizes efficiency improvements over flexibility investments, as they yield higher and more stable returns.

Another significant barrier is that **previous experiences with flexibility participation yielded disappointing financial returns** (*Fo9*). The company had expected higher earnings from flexibility provision, but actual revenues were only one-third of the predicted value (E3.1). This lack of financial reliability discourages further investment in flexibility, as past performance has demonstrated that revenue forecasts can be overly optimistic.

A further economic challenge is that **spot market price spreads are too small** to make flexibility profitable (Fo10). While price fluctuations in electricity markets drive demand-side flexibility opportunities, these spreads are often not large enough to justify modifying sugar processing schedules. Additionally, CO_2 taxation further complicates the flexibility business case. If the refinery needs to increase fossil fuel use to provide flexibility, it raises its CO_2 emissions, triggering additional CO_2 emission certificate costs (E3.2). Since CO_2 prices are expected to rise in the coming years, these indirect penalties erode the profitability of flexibility even further.

They also foresee **decreasing profitability in the ancillary service markets** (*Fo11*). While theoretically possible, ancillary service participation is not a strategic priority and is never included in core business case calculations (E3.3). The company only considers these revenues if an installation is already in place and can participate at minimal additional cost.

However, given the uncertainty in future market prices and regulatory changes, they do not view ancillary services as a long-term, reliable revenue stream.

Another factor influencing flexibility adoption is the **overall economic slowdown in Europe** (*Fo12*). Economic downturns directly affect investment approvals, as companies become more risk-averse and focus on core operational needs rather than non-essential projects like flexibility (E4). During economic upswings, companies are more open to approving new investments, but in times of financial instability, flexibility projects are deprioritized. Instead, they are framed within sustainability efforts, which receive investment only when budgets allow.

Another, related, barrier is that the **CAPEX for new investments is too high** (*Fo13*). Like many industrial companies, Tiense Suiker follows a strict budget approval process, where projects must demonstrate clear financial returns to receive funding (E4, E5). If a flexibility project requires substantial upfront investment, it is less likely to be approved, particularly when competing with efficiency and production-focused investments that offer shorter payback periods.

Another major economic constraint is that **spreading the beet campaign over a longer period to introduce flexibility leads to higher costs** (*Fo14*). Since sugar refining depends on continuous operation, any extension of the campaign requires additional labor, energy, and operational expenses. For example, each additional day in the beet campaign costs the company additional OPEX costs, meaning that even minor schedule adjustments can significantly increase overall processing costs (E6). This financial penalty limits the potential for flexibility, as the cost of prolonging operations often outweighs the economic benefits of market-driven flexibility participation. Adding to the operational costs is the **procurement rigidity and financial risks from forecast deviations** (*Fo17*). Electricity procurement is centrally managed, and each year, the company must make a forecast of monthly electricity consumption, which is then purchased through a combination of baseload contracts, hedging, and spot market exposure. Problems arise when less electricity is consumed than forecasted, as the surplus must be sold back to the market, often at a financial loss (E6).

Flexibility in beet processing **does not just affect the refinery but also impacts farmers** *(Fo15*). Farmers are paid based on sugar content and quality, meaning that delaying beet processing due to flexibility measures reduces their income (E8). If the beets remain in the field longer, their sugar concentration decreases, leading to lower payouts for farmers and less sugar being processed than originally predicted. This creates a supply chain conflict, where flexibility-driven processing delays negatively affect upstream suppliers, making it an unfavourable strategy for both the refinery and the agricultural sector.

A first major regulatory issue is the **conflict of flexibility provision with grid fee regulations** (*Fo18*). If more power needs to be consumed or injected for flexibility provision, this comes at a cost. Injection or load peaks define the monthly or yearly tariffs that need to be paid. A higher than normal peak caused by flexibility provision hence causes additional costs (R5). For example, if a load increase for a short-term flexibility service triggers a new annual peak, this can have long-term cost implications on the tariff side, outweighing the financial benefits of the flexibility event itself. This creates a disincentive to activate flexibility, especially when the tariff system penalizes temporary but necessary peaks.

Another regulatory barrier is the **conflict of flexibility with energy efficiency regulations** (*Fo19*). Providing flexibility can result in less efficient operation, increasing energy use per ton of product and reducing overall efficiency metrics (R6.1). This not only undermines reaching internal energy performance objectives, but also affects CO_2 balances and emissions-related costs. For example, a lower efficiency may require the purchase of additional CO_2 allowances, especially if carbon prices rise. The sugar refinery thus faces a regulatory trade-off between flexibility and energy efficiency compliance, with no clear framework to reconcile both objectives.

Moreover, there are **penalties for not providing reserved flexibility** (*Fo20*). These penalties are part of regulated market arrangements, such as balancing or ancillary services, and are imposed when a contracted flexibility provider fails to deliver the agreed load adjustment upon request (R7). At the sugar refinery, this creates a regulatory risk: the company may be technically willing to offer flexibility, but given the nature of continuous sugar refining, unexpected disruptions (e.g. equipment failure, raw material delays) could make delivery uncertain. The company therefore stresses the need for early-stage clarity on how and when penalties are applied. For example, if they were to offer a certain amount of flexible capacity during the beet campaign and one day fail to deliver due to operational constraints, they risk a contractual penalty — even if the failure was due to reasons beyond their control. Without a clear understanding of how the penalty framework functions, including tolerance margins, notification windows, and force majeure provisions, they are hesitant to engage in flexibility contracts.

Subsidies at the Belgian/Flemish level for providing flexibility are too low compared to other EU member states (*Fo21*). Unlike countries such as Germany, where industrial electrification and flexibility receive generous OPEX and CAPEX support, Flanders offers limited financial instruments for flexibility projects (R11). For example, a sister company in Germany received €227 million in government support for a single factory[3], while in Flanders, currently only €70 million is allocated for the entire industrial sector (ref. Klimaatsprong subsidy program for electric boilers and heat pumps[4]). Moreover, no dedicated OPEX support mechanisms exist for flexibility services, making it difficult for companies like the sugar refinery to justify investments in expensive electrification projects or process automation that would enable participation in flexibility markets.

The **changing political climate** (*Fo22*), represents an overarching regulatory barrier. Frequent shifts in policy priorities, unclear long-term energy strategies, and uncertainty around future regulatory obligations create a hesitant investment climate (R13). This makes companies reluctant to commit to flexibility projects that require multi-year investments, especially when policy frameworks could change mid-project, potentially altering the economic or compliance landscape.

On the organisational side, the sugar refinery's operations are tightly aligned with the beet campaign, and spreading the evaporation or crystallization processes over a longer period—required for introducing flexibility—would necessitate **significant restructuring of workforce planning** (*Fo23*). Personnel schedules are currently optimized for the September–January production window. Any extension would disrupt the planning system and require reallocating or rehiring staff, leading to additional costs and administrative complexity (O1).

Organizational approval of flexibility-related investments is constrained by **strict internal payback requirements** (*Fo24*). While many flexibility and energy investments show payback periods of 7–9 years, the company expects a 2–4 year return window for project approval. This short-term financial focus effectively blocks longer-term investments, even when they offer strategic or sustainability benefits (O2).

Furthermore, energy management, and particularly **flexibility**, is **not a top priority at the corporate management level** (*Fo25*). Although sustainability is a strategic objective, it is primarily interpreted through the lens of energy efficiency, which can at times conflict with flexibility objectives. Since flexibility can temporarily reduce energy efficiency, it is seen as undermining sustainability KPIs, despite potential system-level benefits (O4). The company's strong performance in energy efficiency is also a cornerstone of its sustainability image, one that is actively used in product marketing and external communication. As a result, there is significant hesitation to adopt flexibility strategies that could temporarily erode these efficiency

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[3] https://www.klimaschutzvertraege.info/lw_resource/datapool/systemfiles/elements/files/b1904cbd-0651-11f0-a8e4-a0369fe1b534/live/document/BMWK_A4-Template_Projektsteckbriefe_bf_final.pdf

[4] https://www.vlaio.be/nl/nieuws/70-miljoen-voor-transitiecontracten-klimaatsprong-investeringen-grootschalige-elektrische-boilers-en-warmtepompen#:~:text=maken%20tegen%202050.-,Programma%20Klimaatsprong,een%20steunperiode%20van%2010%20jaar.

metrics, for fear of diluting the company's green narrative and compromising its competitive positioning in a market that increasingly values sustainability credentials.

Reflecting this mindset, there is currently **no integration of flexibility metrics into the company's KPIs** (*Fo27*). Operational success is measured primarily by production output and energy efficiency, not by participation in flexibility markets or contributions to grid services (O5). As a result, local teams lack both the incentives and the visibility to pursue flexibility initiatives.

Adding to this challenge is the fact that flexibility remains a new and unfamiliar concept within the broader corporate culture. The **mother company remains conservative and cautious** to embrace the flexibility narrative (*Fo26*). Flexibility is still a new and unfamiliar concept in the corporate culture, and it will take time before its strategic relevance is fully understood and supported (O4, B4).

This rather conservative attitude towards flexibility also has its effect on the energy procurement strategy. In particular as the **electricity procurement is managed at the level of the mother company, limiting the autonomy** of the Belgian processing plant to develop and test local flexibility strategies (*Fo28*). This centralization of power purchasing (O6) means that flexibility potential at the site level often remains untapped, as decisions are made with standardization and procurement efficiency in mind, not responsiveness to market signals.

Moreover, often there are also **multiple decision makers involved in the project decision making process** (*Fo29*). This results in lengthy discussions with few concrete outcomes (O8). Flexibility projects often require longer lead times and strategic alignment, making them vulnerable to staff turnover, shifting priorities, and internal coordination delays. In contrast, projects that must be executed quickly tend to get prioritized, simply because they can bypass extended internal negotiation processes (O8).

Flexibility provision would require a clear **advance notice-time procedure** with staff allocated **to monitor and adjust production processes as needed,** which is currently **lacking** (*Fo30*). Currently, the company is not organized to respond dynamically to flexibility signals, and no procedures are in place to support rapid reallocation of operational tasks (O10). Building this capability would require significant internal reorganization and capacity building.

The sugar refinery also faces several behavioural barriers that hinder the adoption of flexibility. These barriers stem from perceptions, cultural attitudes, and trust-related concerns, both within the company and in its surrounding environment. A first behavioural barrier arises from **community perceptions** surrounding new industrial initiatives (*Fo31*). For example, the sugar refinery explored the possibility of investing in a biomethane plant that would have also enabled increased flexibility. However, the surrounding neighbourhood opposed the project, citing concerns over potential odour nuisance. As a result, the project was abandoned. Such negative perceptions can complicate the permitting process and discourage companies from pursuing innovative or sustainability-oriented investments, even when these projects are environmentally sound (B2).

Next, within the company, there is **notable scepticism toward the use of fully automated systems** in the context of flexibility (*Fo32*). Process operators expressed concern about losing control over critical aspects of production. There is uncertainty about how much autonomy such systems would have, what fallback or overrule options exist, and whether automation could lead to unintended disruptions (B3). These doubts create resistance to the implementation of digital tools that are essential for real-time flexibility provision.

More broadly, there is a **perceived inconvenience associated with implementing flexibility** by internal staff (*Fo33*). Employees anticipate that flexibility initiatives will require changes to routines, new responsibilities, or disruptions to established workflows. Getting all teams aligned behind these changes will require communication, coordination, and trust-building, especially in a production environment where stability and predictability are core values (B4).

Next, there is a **reluctance to involve external partners** in operational processes that relate to flexibility (*Fo34*). In some flexibility setups, such as those services which require a flexibility service provider (FSP) or aggregator as an intermediary, a third party may need to access, steer, or influence part of the energy management system. For this to work, that party needs to have the full trust of the company, particularly in terms of data security, system reliability, and operational boundaries. At present, this trust has not yet been fully established, which creates another barrier to engagement with external flexibility service providers (B5).

Subsequently, a number of informational barriers were mentioned. To start, there is a **lack of transparency and asymmetry of information** (*Fo35*). The sugar refinery was once approved as a flexibility provider, but was never selected to deliver flexibility for balancing services, and received no feedback on why they were excluded. This made it impossible to improve or adapt their offer. In contrast, other companies, often larger or more energy-focused, are well-informed and more successful in these markets. For the sugar refinery, the absence of clear market feedback creates a blind spot, leaving the team disempowered to make adjustments or build experience (I1).

There is also significant **uncertainty regarding the financial implications of flexibility participation** (*Fo36*), particularly in the context of volatile energy markets and **price forecasting** (*Fo37*). Since the company does not specialize in energy trading, it is difficult for them to predict the potential value of flexibility and compare it against risks, including hidden costs or unforeseen penalties (I2, I2.1). This uncertainty leads to hesitancy in committing to flexibility projects, especially in a conservative industrial setting where cost predictability is key.

Additionally, there is **uncertainty about future regulations and legislative developments** (*Fo38*). For non-energy-intensive industries like the sugar refinery, it is unrealistic to expect companies to invest substantial internal resources into deciphering fragmented, overlapping, and often ambiguous policy frameworks (I3). It is particularly challenging to distinguish between Belgian federal legislation and Flemish or regional policies, and to determine the anticipated future impact of these policies. Moreover, the relevant information is spread across multiple disconnected platforms, including regulatory websites, sectoral newsletters, and market operator portals, making it extremely difficult to obtain a clear, up-to-date overview, let alone anticipate upcoming developments. This lack of centralized and coherent communication further discourages companies from engaging in flexibility initiatives, especially when policy shifts may fundamentally change the regulatory landscape without sufficient warning. In contrast, larger industrial players often have dedicated in-house experts or legal advisors who can track and interpret these developments in real time; an advantage which smaller players like the sugar refinery typically lack.

Compounding this issue is the **unclear interpretation of existing legislation** (*Fo39*). Since flexibility provision lies outside the core expertise of most food companies, participation is only feasible when rules and procedures are unambiguous and easy to implement (I3.1).

Another key barrier is the **uncertainty regarding the allocation of roles and responsibilities among stakeholders** (*Fo40*). It is often unclear who does what, who holds the obligations, and what the expectations are for the flexibility provider. For instance, if the sugar refinery provides flexibility via an aggregator, it is currently not clear for them who is responsible in case of non-delivery—the company itself, the aggregator, or the Balancing Responsible Party (BRP)? This ambiguity in roles and responsibilities makes it difficult to assess risks, complicates contract negotiations, and discourages them from participating in flexibility schemes (I3.2), especially since they lack in-house legal or regulatory expertise.

Even before a project is launched, **analyzing its feasibility and financial logic** is already **costly and involves a high level of uncertainty** (*Fo41*). The combination of internal knowledge gaps, multiple uncertainties, and lack of reference cases makes internal project evaluation a major hurdle (I7). For the assessment of a business case for flexibility projects at the sugar refinery a robust cost-benefit analysis proved challenging. This is due to the intricate combination of multiple influential variables; the seasonal nature of operations, uncertainty around activation frequency and volume, the complex interaction with CO_2 certificate costs, the impact on grid fees, and conflict with pre-purchased electricity contracts.

Finally, there is a **lack of awareness among internal decision makers** (*Fo42*). This is particularly relevant for non-energy-intensive sectors like food processing. Many internal decision-makers (both at the Belgian sugar refinery as with the mother company) have limited understanding of flexibility markets, and there is insufficient targeted information available to guide them. To enable broad participation, the sugar refinery misses accessible, tailored information on where to find price signals, how to enrol, how to align participation with existing energy contracts, and what penalties or obligations might apply (I8). Currently, they perceive that most attention is directed at large players, while smaller industrial actors are left behind, despite their potential to contribute to system flexibility.

Extrapolation from company to sector level

The barriers observed at the sugar refinery can be extrapolated to the food sector in general insofar as it reflects structural properties that many food plants share, while recognising that their relative weight varies by sub-sector. Food production is governed by strict product quality and safety requirements, hygiene regimes and validated procedures. Under these conditions, technological constraints often dominate: modest deviations from set points can impair quality and start–stop cycles can be costly. On the economics side, energy efficiency typically outperforms demand response on net present value, enabling CAPEX for flexibility is material, and expected flexibility value carries uncertainty that is hard to quantify for smaller plants. Organisationally, flexibility is rarely embedded in KPIs or governance, procurement is often centralised, and multi-stakeholder decision processes slow adoption. Information and competence gaps amplify these effects where market transparency is limited and evaluation tooling is not yet standard.

Several features of the sugar case are more specific to campaign-based thermal processing and should not be generalised without care. Near-100 percent utilisation during a fixed campaign window, perishability of the raw material that blocks upstream buffering, and the high cost of extending the campaign all suppress flexibility in ways that are stronger for sugar than for many other food companies.

The sector is heterogeneous and the expression of barriers differs by archetype. Cold-chain dominated sites, such as large cold stores and frozen foods, often have the widest electrical flexibility window because thermal inertia allows pre-cooling, defrost scheduling and temperature band optimisation, subject to HACCP constraints. Batch fast-moving consumer goods, such as bakeries, confectionery and beverages, can embed scheduling flexibility around shifts, proofing or packaging with careful quality assurance; organisational alignment and KPI design tend to be the primary hurdles. Continuous thermal processes with some buffering, for example dairy evaporation and milk powder, sit between these extremes: interruption tolerance is limited, yet targeted options such as thermal storage, steam-system optimisation and time-of-use alignment are feasible once metering and control prerequisites are in place.

2.4.2.4 Iron and Steel sector

Figure 2-17 presents the fishbone diagram for barriers to industrial flexibility for the iron and steel sector. The barriers are explained in more detail below.

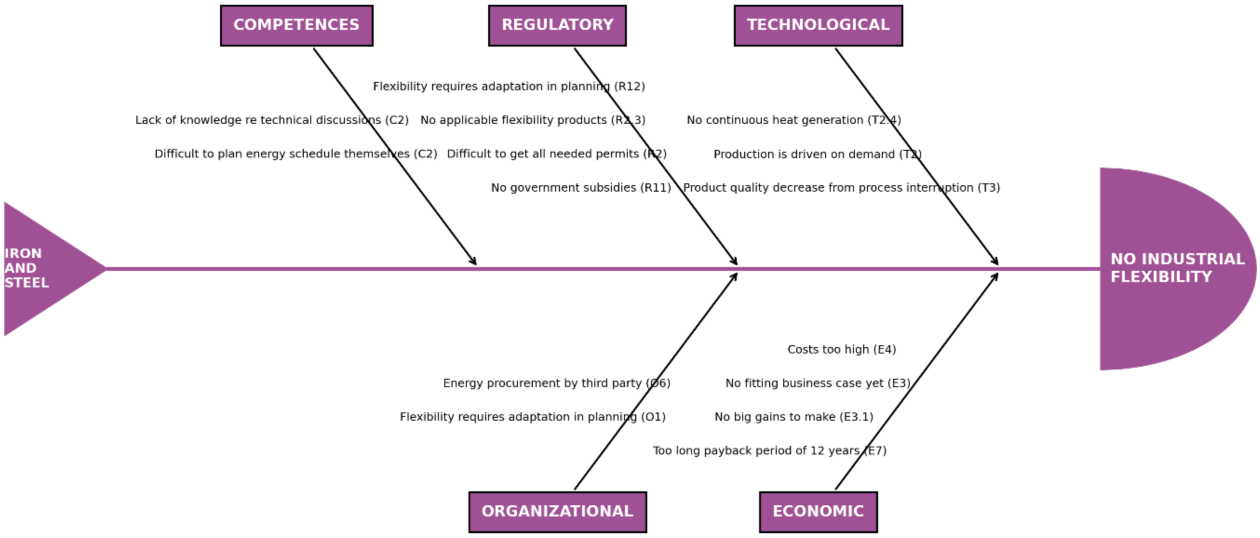

Figure 2-16: Fishbone diagram of barriers to industrial flexibility for the iron and steel sector

In the steel plant, the main heat-generating and high-load units, two EAFs and two AOD converters, **operate in batch cycles, concentrating energy use and heat release into short, discrete phases rather than a steady profile** (Ir1). Because the bulk of consumptive power sits in a time-critical step that is tightly coupled to metallurgical quality, tap-to-tap timing, and shop logistics, scope for modulation during that phase is minimal. Shifting or curtailing it risks scrap freeze, off-spec chemistry, refractory wear, or extended cycles, so only small intra-batch nudges or occasional deferrals between heats are feasible. The result is a narrow, sequence-dependent demand-response band, with limited duration and volume. While some smaller installations do provide more stable heat outputs, their lower installed power makes their contribution to flexibility marginal (T2.4).

Additionally, **the production process is highly demand-driven**, making flexible operation more difficult to schedule (*Ir2*). In EAF–caster–rolling routes, customer orders drive a finite-capacity schedule with "frozen" horizons. The 2-month lead time reflects many tightly coupled, sequence-dependent steps and bottlenecks (caster, hot mill), not idle slack. Once heats are sequenced into grade campaigns and downstream slots, hour-ahead or intra-day price signals cannot be followed without breaking sequences, creating extra reheats and changeovers, upsetting metallurgical windows, growing WIP (Work-in-Progress), and risking due-date penalties (T2.4).

Thirdly, interrupting the production process for flexibility reasons would **accelerate equipment degradation** (*Ir3*). For instance, interrupting an EAF exposes the refractory lining to rapid cooling and subsequent re-heating, creating steep thermal gradients. These thermal shocks, together with slag and steel solidifying against the hot face and then being re-melted at restart, cause spalling and cracking. The result is accelerated wear and poorer insulation performance, which shortens lining life and raises energy use per heat (T4).

From an economic perspective, the company identifies **too limited financial incentives to engage in flexibility** *(Ir4).* The company reports that existing flexibility products yield too limited revenue for them, and there is thus no strong business case for altering operations based on energy price signals. While there is a workflow for demand-side measures like temporary shutdowns during peak price moments, the remuneration of the provided flexibility, is small and does not outweigh the costs for the provision of that flexibility (e.g. the imbalance costs incurred from market deviations remain too high) (E3.1).

Moreover, **investment decisions for flexibility projects are hindered by high upfront costs** (Ir6). Due to the current unfavourable economic climate in the (stainless) steel industry, many capital-intensive projects have been put on hold, regardless of their potential to deliver long-term energy savings or improve flexibility (E4). Another major obstacle is the **long payback periods** associated with these projects (*Ir7*). Some initiatives, such as a planned Organic Rankine Cycle (ORC) installation, were ultimately abandoned because the projected return on investment exceeded 12 years. Projects with similar financial profiles have faced the same fate. Internally, the company applies a strict payback threshold of 7 years, a requirement that flexibility projects often fail to meet (E7, O2). As a result, the financial case for flexibility investments remains weak under current conditions, despite their technical feasibility or strategic relevance.

A number of regulatory challenges also hamper flexibility implementation. For example, the company has faced **difficulties obtaining necessary project permits**, including for a planned solar PV installation (*Ir8*). In this case, the installation was to be connected via a direct line. Such a direct line does not require a permit when located entirely on-site, but the proposed connection route required crossing public grounds, a canal managed by Flemish Waterways. Although the technical solution involved underground cabling beneath the canal, the project still needed formal approval from the waterway authority. Ultimately, this approval was not granted, which effectively blocked the realisation of the direct line (R2). While an alternative solution exists, i.e. connecting the PV installation to the public grid via a separate EAN, this would eliminate the possibility for direct self-consumption. As a result, the company would be subject to additional taxes, levies, and grid fees on the entire volume of electricity generated, significantly undermining the project's financial viability.

There is also a **lack of government support or subsidies** for flexibility-related investments (*Ir9*). While public funding mechanisms do exist for broader energy efficiency or renewable energy projects, flexibility remains largely unsupported as a distinct investment category (R11).

Another issue relates to **the personnel planning and process continuity** (Ir10). Furnaces can only operate when operational staff are on site and raw materials are available. If actions need to be taken spontaneously, e.g. responding to low-price periods, production may not be feasible due to the absence of labour forces and material stock (O10, T2.4). This makes real-time flexibility extremely difficult without significant operational preparation.

From an organizational perspective, the company also faces challenges due to the **centralized energy procurement strategy** (*Ir11*). Electricity is not procured independently but via an affiliated company, who purchases the big majority on the day-ahead market and the remainder smaller portion under fixed contracts. While this provides some exposure to market prices, it also means the company itself has limited control over procurement decisions or flexibility engagement (O6).

Lastly, there are competence-related constraints. Internal project teams are deliberately kept small, partly due to the cyclical and cost-sensitive nature of the steel sector, which encourages lean staffing strategies during periods of market uncertainty. While this approach supports operational efficiency, it comes at the cost of **limited engineering bandwidth** and **scarce in-house expertise** for complex, cross-cutting topics like energy flexibility *(Ir12*). Project proposals often lack the technical depth or economic analysis needed to gain approval, not because of a lack of interest, but due to a shortage of available staff to develop, assess, and defend the business case. This slows decision-making and sometimes causes promising initiatives to be postponed or shelved, not due to strategic misalignment but simply due to capacity constraints (C1).

Moreover, there is **no structured focus on energy-based production scheduling** within the current organization (*Ir13*). Market dynamics such as energy prices or flexibility services are currently not considered input factors in the planning of the steel production process. In practice, the scheduling of production is shaped by internal production factors such as labour availability, material logistics, maintenance planning, and the complex interlinkages between different process steps. These factors already make the planning exercise highly intricate, and the addition of energy-related considerations, such as optimal dispatch times or flexibility activation windows, is not part of the current framework. Energy is treated as a fixed input of production, rather than a dimension that can be optimized. As a result, potential opportunities to align production schedules with energy market conditions remain untapped, simply because they fall outside the traditional planning mindset (C2, C4, R7).

Extrapolation from company to sector level

A key characteristic that generalises across most Belgian melt shops is the presence of a narrow, sequence-dependent flexibility window, rooted in batch metallurgy and finite-capacity scheduling. The majority of electrical demand concentrates in time-critical stages of the electric arc furnace (EAF) cycle, where only minor, preplanned adjustments are technically feasible. Once heats are sequenced into grade-based campaigns and aligned with downstream slotting, responding to short-notice signals becomes increasingly difficult due to the risk of cascading impacts on product quality, work-in-progress stability and delivery reliability. Process interruptions further exacerbate operational stress by accelerating wear on high-temperature assets and increasing energy consumption per heat.

On the economic and organisational side, flexibility faces additional structural barriers. Capital expenditures required to enable flexible operation often compete directly with investments in core metallurgical capabilities. Anticipated revenues from flexibility services remain relatively modest compared to the production and quality risks involved. Moreover, flexibility considerations are rarely embedded in performance indicators, operational planning or investment evaluation frameworks.

The specific configuration of stainless steel production, particularly the combination of EAF with argon-oxygen decarburisation (AOD) refining, adds further constraints that should not be overgeneralised. Stainless operations typically exhibit narrower alloy tolerances, longer refining durations and higher sensitivity to thermal and chemical disturbances. These characteristics render intra-cycle modulation even more limited than in many carbon EAF mini-mills.

Flexibility barriers and associated opportunities differ across steel sector subsegments. Carbon-based EAF mini-mills, while also operating under batch and sequence constraints, often have comparatively more leeway in auxiliary systems or rolling schedules, allowing for modest improvements in day-ahead planning or plant-level load management. In contrast, integrated BF-BOF facilities face a distinct barrier profile, with less exposure to sharp EAF load peaks but more potential leverage in managing by-product gas networks, stove operation, CHP units and rolling lines. These options remain constrained by tight stability and environmental requirements. Finally, finishing-only plants and service centres typically have greater temporal flexibility over multi-day horizons. However, their smaller load volumes translate into lower absolute system value.

2.4.2.5 Non-ferrous metals sector

Figure 2-17 shows the fishbone diagram with barriers to industrial flexibility for the non-ferrous metals sector. The barriers are explained in more detail below.

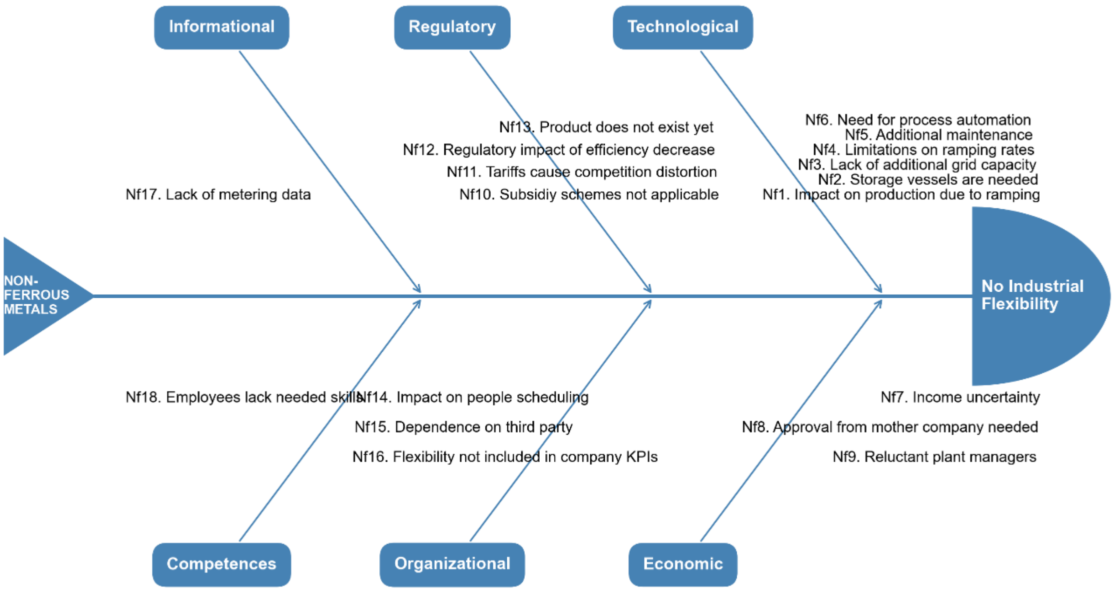

Figure 2-17: Fishbone diagram of barriers to industrial flexibility for the non-ferrous metals sector

The most critical technological barrier is the **impact of ramping up and down production output** (*Nf1*). Unlike many industrial processes, the production of zinc is highly sensitive to power modulation. If the company were to participate in flexibility markets and adjust its electricity consumption in response to market signals, this would directly lead to temporary reductions in zinc output. Given the company's scale and role in the zinc market, such production drops could influence zinc prices, especially if flexibility activation coincides with periods of high demand or constrained supply. To avoid such market interference, the company would need to rely more heavily on its virtual battery system, which allows it to modulate electricity use while maintaining a more constant production flow. However, under current conditions, the capacity of this virtual battery is insufficient to fully absorb the required load shifts. An estimated 32% increase in virtual battery capacity would be needed to compensate for the production disruptions caused by ramping (T1).

Secondly, **storage vessels are needed to assure flexibility can be delivered during longer periods** (*Nf2*). In a continuous and tightly integrated production process like zinc electrolysis, power adjustments—whether ramping up or down—can cause imbalances between the upstream and downstream steps. Without intervention, this would require making the entire production chain flexible, which is often technically unfeasible, economically unattractive, or operationally disruptive. To avoid this, intermediate buffer vessels are needed to decouple process stages. These vessels act as a form of process storage, absorbing fluctuations in production output or feedstock input when the power load is modulated for flexibility purposes. For instance, if the front-end of the process ramps down due to a flexibility request, the buffer can continue supplying material to downstream stages, avoiding a complete plant-wide adjustment. The capacity of these buffers will ultimately define how much flexibility can be offered (T2.2, T2.4).

Another major technological and infrastructural constraint is the **limited availability of grid capacity** (*Nf3*). The company is connected to the transmission system operator (TSO) grid, but the connection is fully saturated, leaving no room for additional contracted capacity to support further electrification or expand flexibility operations. In response to growing grid congestion, non-firm or flexible grid connections are being introduced as a potential solution.

Under such arrangements, grid users are connected based on available capacity that varies over time. For this zinc company, being forced to operate under such a flexible connection implies losing control over when electricity is available, which could affect not just output stability but also equipment health and overall process integrity. To mitigate these risks, the company would require a clear and predictable contractual framework, detailing exactly when curtailment could occur, how much notice is provided, and what compensation or backup options are in place. At present, this clarity is lacking—making it impossible for the company to confidently adapt production planning or justify investments under such uncertain conditions (T2.5).

Ramp rate limitations also pose a problem (*Nf4*). The system is constrained by a voltage limit of 515 V and exceeding this limit could damage equipment. Rapid ramping risks breaching this threshold, and currently the ramping is managed manually and slowly. Fast power ramps create transient over-voltage that risks tripping or damaging equipment, so ramps are currently executed manually and conservatively. Currently, participation in fast-response products remains constrained (T2.7). Until controls are in place, non-delivery exposure under market rules is material (R7).

Moreover, frequent ramping **accelerates equipment wear and tear on critical electrical and electrochemical components** (*Nf5*). This is particularly evident in equipment such as transformers, rectifiers, and anodes, all of which are sensitive to frequent load changes. For example, transformers and rectifiers are designed to operate most efficiently under stable loads. When subjected to continuous cycling, especially at high frequencies, they experience thermal stress, and elevated risk of premature component degradation. This leads to more frequent maintenance interventions, increased downtime, and the need for earlier replacement, which in turn raises operational expenditures (OPEX) and affects overall production reliability (T4). In addition, anodes used in zinc electrolysis are vulnerable to mechanical and thermal stress caused by inconsistent electrical loads. Rapid or irregular ramping can cause bending of the anodes, increasing the risk of short circuits in the electrolysis bath. Such events not only reduce process efficiency but also pose safety risks and potential production losses. Replacing anodes is costly, and their deformation can have cascading effects on product quality, efficiency, and process stability.

Another barrier involves the **cooling system** for rectifiers and electrolytic solution, which currently **lacks automation** (*Nf6*). The rectifiers and the electrolytic cells are thermally sensitive. Without automated cooling control, changes in electrolysis current for flexibility cause temperature swings in the rectifiers and in the electrolyte. Temperature shifts change cell resistance and thus the DC voltage required at a given current. If current is ramped faster than the cooling loops can remove heat, the control system can overshoot temperature and voltage limits, which risks tripping or equipment damage. To activate flexibility safely, the plant needs coordinated automation that links the rectifier setpoint, ramp-rate limits, and cooling capacity, with hard interlocks. This requires additional software logic and IO: reliable temperature and flow sensing on rectifiers and cells, dI/dt governors tied to measured coolant capacity, maximum cell voltage supervision, and fail-safe actions (hold, controlled ramp-down) when limits are approached (T5.1).

From an economic perspective, the main issue is **income uncertainty**. Flexibility requires **high upfront investment (CAPEX)** (e.g. for buffer capacity like the virtual battery project or for automation and control systems) but the **long-term financial return per MW of flexibility remains unclear** (*Nf7*). The lack of transparent, reliable information on future market revenues, the volatility of activation prices, and the absence of guaranteed compensation schemes make it difficult to build compelling investment dossiers that would meet internal financial criteria (E4, E7, I2, I7).

In addition to internal investment hurdles, flexibility initiatives require **approval at group level**, where perceived risks and limited confidence in the business case constrain decisions (*Nf8*). At group level, capital allocation follows standard portfolio rules with limited visibility of site-specific operational constraints and risk controls. The unfamiliarity of flexibility as an asset class, together with long approval timelines, leads to conservative assessments and deprioritisation versus conventional CAPEX projects, delaying or blocking otherwise feasible site-level initiatives (Nf8, E8, O7, O8, B3).

Moreover, **plant operators and process staff themselves are not always supportive of flexibility projects** (*Nf9*). A key driver is KPI misalignment: prevailing performance metrics emphasise steady-state efficiency, yield, and energy-per-ton, so temporary deviations during ramping are recorded as underperformance. Flexible operation also requires more frequent monitoring and interventions, adding cognitive load and disrupting established workflows. In this context, operators can perceive flexibility as more work for equal or lower evaluated performance, especially where internal KPI frameworks do not recognise flexibility-related outcomes or provide clear operating envelopes (B1, B3).

The company also faces multiple regulatory challenges that hinder flexibility deployment. A core issue lies in the **misalignment between subsidy schemes and the operational reality of electro-intensive industries** (*Nf10*). For instance, while newly installed wind turbines receive a 15-year qualification period under the Belgian Capacity Remuneration Mechanism (CRM), electrolysers, despite being critical flexibility enablers, are only granted one-year contracts. This shorter qualification period reduces investment certainty, distorts competition, and effectively discourages the deployment of flexible electrolysis infrastructure (R2).

Another significant hurdle is the **unequal treatment in grid tariff structures** for different types of grid users (*Nf11*). While large electricity consumers are subject to high transport tariffs, producers and certain battery storage installations at the transmission level often pay significantly less, or nothing at all. This unequal treatment becomes problematic when flexibility provision results in additional consumption peaks, as these peaks directly influence annual or monthly grid fees. Without tariff exemptions or adjusted methodologies, flexibility can inadvertently lead to higher grid costs, weakening the business case and discouraging participation (R1, R5).

A more nuanced but equally important issue is the **efficiency decreases** when flexibility is activated (*Nf12*). As such that is not a big problem, however, it causes issues for reporting of ‘Energy Policy Agreements’[5] (EBO). EBOs are aimed at ensuring that as many energy-intensive companies as possible become and remain leaders in the field of energy efficiency. The participating companies thus contribute to the realization of the Flemish CO_2 and energy efficiency objectives [125]. Hence, when energy efficiency decreases under a valid EBOs, the Flemish Government will start asking questions (R6.1).

In terms of market design, there is a notable **product gap** (*Nf13*). While short-term balancing products such as aFRR and mFRR exist, and CRM provides long-term capacity support, there is currently no dedicated market product for long-duration flexibility, specifically, the kind enabled by virtual batteries or large-scale electrochemical storage. This creates a mismatch between the asset’s technical capabilities (e.g. sustained delivery over 10 hours) and the available market channels to monetize that capability. In Germany, for instance, a Long Duration Energy Storage (LDES) auction model addresses this issue by creating a tailored procurement mechanism, a model that could serve as inspiration in the Belgian context (R2.3) [126], [127].

From an organizational standpoint, ramping up and down introduces **volatility into workforce scheduling** (*Nf14*). Additional personnel are needed to manage increased operational activity during flexible production periods, while these same workers may be underutilized during low-load phases. This volatility complicates planning, particularly when energy price signals are unpredictable and activations are sudden. Balancing personnel needs with flexibility activation

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[5] ‘Energiebeleidsovereenkomst’ or ‘EBO’ in Dutch.

requests requires agility the organization currently lacks, particularly in terms of reserve staffing or reskilling (O1, O10, E6, R12).

Another organizational dilemma involves the **management of voltage peaks**, which can occur during flexibility activations (*Nf15*). One strategy to mitigate these peaks is through the MVAr (megavolt-ampere reactive) signal, which allows for dynamic voltage control by coordinating reactive power compensation—often in collaboration with external assets such as nearby PV parks. These PV installations can inject or absorb reactive power to help stabilize voltage, but they are operated by third parties, meaning the company has limited control over their availability, responsiveness, or prioritization. Alternatively, the company could invest in internal active filters, which provide precise and autonomous voltage regulation. However, these filters represent a major capital expenditure, often requiring investments in the multi-million-euro range. While active filters ensure full control over voltage stability and system reliability, their high cost makes them difficult to justify purely for flexibility participation. This creates a strategic trade-off between cost efficiency and operational autonomy.

Furthermore, company **KPIs remain misaligned with flexibility objectives** (*Nf16*). As in many industrial firms, internal performance metrics emphasize output, efficiency, and stability, while participation in demand response or ancillary services is not yet rewarded. This means that local teams lack both the mandate and the incentive to proactively explore flexibility, particularly when such participation may increase complexity or pose risks to production targets (O5).

On the information front, the company reported **incomplete and outdated internal documentation and data**, including metering data, vibration measurements, and historical equipment performance logs (*Nf17*). These data gaps limit the ability to assess technical feasibility, estimate asset degradation under flexible operation, or model realistic flexibility scenarios. Internally, the absence of accurate, up-to-date information severely limits the company's ability to define a robust business case for flexibility and quantifying the financial risks. Externally, the lack of high-quality data also complicates collaboration with third parties such as aggregators and grid operators. These actors require precise and consistent baseline data to ensure proper settlement, market participation, and monitoring. If such baselines are unreliable or unavailable, flexibility provision is less straightforward (I4.1, I4.2).

Finally, the company faces a **skills gap** in relation to flexible production management (N*f18*). While operators are highly experienced in conventional, stable operations, few have received training or exposure to operating under variable load conditions. This includes real-time process steering, automation strategy development, and understanding how flexibility activation impacts the production process. This leads to a certain cautiousness toward adopting new operational modes, not so much from resistance to change, but rather from a need for greater confidence, adapted training, and stronger internal support structures (C2).

Extrapolation from company to sector level

For hydrometallurgical routes with large electrolysis trains (for example zinc electrowinning or copper electrorefining), the core mechanisms are broadly shared. Flexibility actions that change cell current quickly destabilise the thermal–electrochemical balance, because heat removal, cell resistance and DC-voltage limits co-evolve with temperature and flow. Absent tightly coupled automation between rectifier set-points, dI/dt limits and cooling capacity, safe ramp envelopes are narrow and slow (Nf4, Nf6). Frequent cycling accelerates wear in transformers, rectifiers and anodes, raising OPEX and outage risk (Nf5).

Where production stages are tightly integrated, intermediate buffer vessels are a prerequisite to decouple sections and avoid propagating a ramp through the entire chain; available buffer volume ultimately caps deliverable flexibility (Nf2).

Several elements in the non-ferrous metals sector barrier analysis should not be over-generalised. Process diversity within the Belgian non-ferrous sector implies distinct barrier profiles and levers. Pyrometallurgical operations that rely on electric or hybrid furnaces face constraints akin to steel: thermal inertia, refractory life and quality windows limit cycling. Here, feasible flexibility is often found in auxiliaries, slow set-point trimming and planned day-ahead timing rather than fast products. Mechanical processing sites such as rolling, extrusion and wire drawing have smaller absolute loads but greater scheduling latitude within days; their bottlenecks are organisational (planning, KPIs) and market transparency for valuing smaller, shorter-duration responses. Complex multi-metal recycling and refining plants sit between these poles; they mix electrolysis sections with thermal units and logistics constraints, so flexibility potential is highly configuration-specific and depends on available buffers and automation maturity.

2.4.3 Barrier relevance

Following the identification of barriers faced by different companies and sectors, the next step in our analysis was to assess their relevance. Each participating company was asked to highlight, for each barrier category, up to three most relevant and least relevant barriers. This approach provides a structured view of how companies prioritize challenges related to industrial flexibility.

Figure 2-18 presents an overview illustrating the relevance of barriers across industrial sectors. In this visualization, blue cells indicate barriers identified as most relevant, while green cells highlight those deemed least relevant.

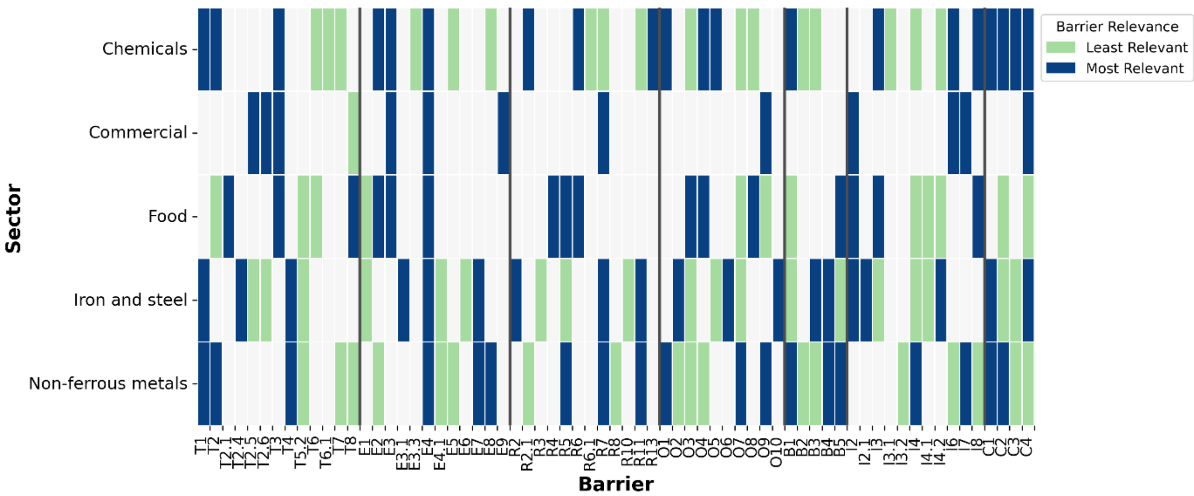

Figure 2-18: Heat map of barrier relevance for the different industrial sectors

A clear pattern emerges regarding how frequently certain barriers are marked as relevant. There is convergence on a small set of constraints, alongside pronounced sectoral divergence in what companies deem material. Across sectors, high upfront investment needs are most frequently marked as critical (E4). This is consistent with the enabling nature of flexibility in industry: meaningful participation typically requires metering, automation, controls integration, storage or process modifications, all of which compete with core business CAPEX. A second cross-cutting theme is the insufficiency or uncertainty of revenues from flexibility (E3). This signal is strong in chemicals, food, commercial data centres and steel, while it is notably weaker in non-ferrous metals, which aligns with the sector case where a more mature flexibility business model is in place.

On the technological side, the risk of product or service quality degradation (T3) is routinely rated as most relevant in process-sensitive environments: food processing, catalytic or thermally constrained chemical units, and data centres where cooling set-points and uptime targets dominate. Together, these three items (E4, E3, T3) form a common core of barriers that recur irrespective of sector.

Beyond this core, the figure expresses sector-specific salience. Commercial data centres recurrently label grid-side constraints as most relevant, in particular local congestion and connection lead times or upgrades (T2.5, T2.6). This reflects an operational reality where siting near customers exposes facilities to over-subscribed urban grids, so connection topology rather than process physics becomes the binding constraint. In contrast, food and several chemical sub-sectors emphasise technological and quality risks linked to start–stop or set-point deviations, whereas grid issues are acknowledged but rarely top-ranked. Iron and steel highlight technological barriers tied to batch metallurgy and equipment integrity, with regulatory and organisational items present but comparatively secondary to process physics. Non-ferrous metals exhibit a different profile again: safe ramp envelopes and equipment degradation dominate relevance, while pure revenue insufficiency (E3) is not as frequently top-ranked given the sector's electro-intensive economics and existing flexibility practice.

An important feature of Figure 2-18 is the set of items that appear as both most relevant and least relevant across different sectors. The risk of missing production targets (E8) is a representative example. In sequence-dependent, campaign-bound or make-to-order environments it is a first-order concern, while in plants with buffering or schedulable auxiliaries it is relegated to the background. Organisational barriers (O-series) similarly show no uniform pattern. Their salience varies widely with company governance, KPI design, procurement centralisation and the maturity of energy management. Informational and competence barriers also vary: firms with in-house energy expertise down-rank them, whereas firms without dedicated capability mark them as highly relevant, indicating a need for differentiated knowledge support and evaluation tooling rather than a one-size-fits-all remedy.

In sum, the analysis supports a two-level interpretation. First, there is a common economic–technological core (E4, E3, T3) that justifies cross-sector measures, such as targeted support for enabling CAPEX and improved transparency and predictability of flexibility revenues. Second, beyond this core, relevance is mediated by sector archetype and site context. In particular, priorities diverge by archetype: firm, predictable grid access is decisive for data centres; quality-preserving control strategies and process buffering are critical for food and parts of chemicals; and protecting equipment life through disciplined ramp-rate limits and maintenance-aware operating windows is central for steel and electrolysis-based non-ferrous plants.

2.4.4 Barrier prioritization

The companies were also asked to prioritize the barriers according to their impact, i.e., the extent to which the barrier affects flexibility, ranging from low to high impact, and timeframe, referring to when the barrier will be relevant (and, hence, will need to be addressed), ranging from short-term to long-term. This exercise allows us to see which barriers need to be addressed with the highest urgency and which type of solutions need to be provided (see Chapter 3).

The scores were plotted in a prioritization matrix, with four quadrants. Barriers with a high impact and short-term timeframe end up in the 'high priority' quadrant, bottom right. Barriers with either low impact and short-term timeframe or high impact and long-term timeframe end up in the 'medium priority' quadrant (bottom left or top right). Finally, barriers with a low impact and long-term timeframe end up in the 'low priority' quadrant, top left. The result of the exercise is shown in a graphical way in Figure 2-19.

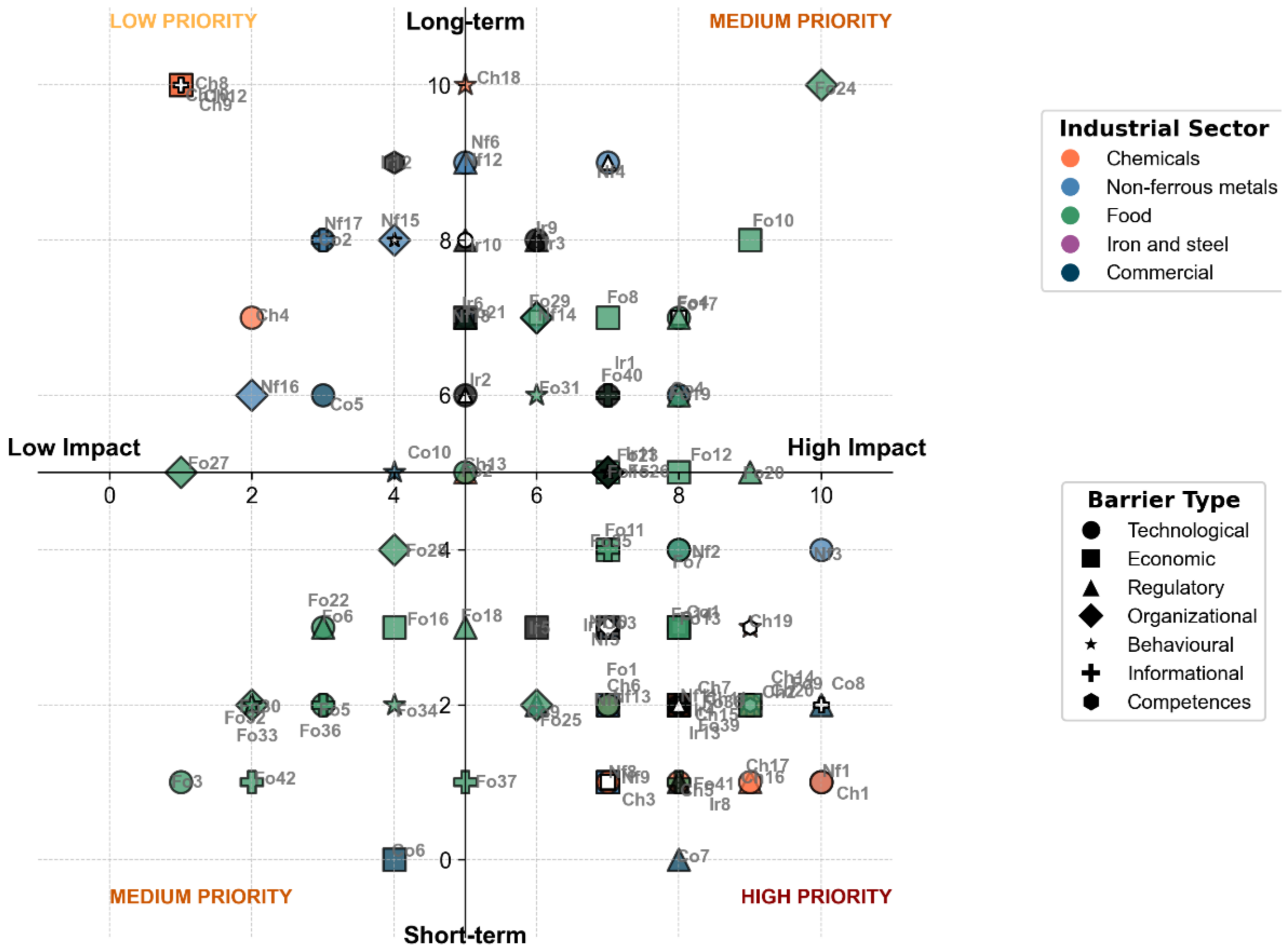

Figure 2-19: Prioritization matrix for the sector barriers

High-priority (short-term, high-impact).

Across sectors, two themes dominate this quadrant. First, grid-side constraints (i.e. insufficient connection capacity, long lead times for upgrades), and uncertainty around flexible/non-firm connections, are repeatedly scored as urgent because they directly cap electrification and the entailing flexibility potential which can be offered today. Second, product/service quality risk is marked critical wherever small set-point deviations jeopardise output (food, chemicals) or service levels (commercial data centres). A third, pervasive item is uncertainty about the value of flexibility (i.e. both revenue sufficiency and predictability). Companies report that without clearer price signals, activation patterns, and settlement transparency, internal investment cases stall even when technical options exist. In electro-intensive processes (non-ferrous) safe-ramp limits also appear in this quadrant because breaches trigger trips, equipment wear, or non-delivery exposure.

Medium-priority (short-term, low-impact).

This quadrant is populated exclusively by food-sector entries and is dominated by organisational, behavioural and informational barriers rather than economic or technical ones. Typical examples are limited awareness of what flexibility entails, reluctance among plant managers and shop-floor staff to adopt new operating modes, and the perceived inconvenience of flexibility interventions in day-to-day production. These items are best understood as procedural frictions that can be resolved relatively quickly through communication, training, KPI tweaks and light process changes. They are attractive quick wins, yet on their own they do not unlock large flexibility volumes and should not distract from the binding constraints in the high-priority quadrant.

Medium-priority (long-term, high-impact).

This quadrant contains barriers from all five sectors and is dominated by technical, economic, and regulatory themes. The items clustered here act as structural enablers: they materially expand feasible flexibility, yet they require multi-year programmes to deliver. Typical examples include enabling CAPEX for metering, automation, controls integration and storage; grid reinforcement and revised connection topologies; and regulatory or tariff adjustments where current methodologies penalise temporary peaks or complicate aggregator–BRP coordination. Firms rate the potential impact of these measures as high, but they also recognise the long delivery path created by permitting, procurement, integration in live plants, outage scheduling, and coordination with DSOs or the TSO. As a result, these barriers are not immediate blockers to day-to-day operations, but they largely determine the ceiling of what industrial flexibility can become over the medium term.

Low-priority (long-term, low-impact).

Few items land here, and those that do are typically context-specific cultural or reputational concerns that matter locally but neither block near-term participation nor change system value at scale. They can be sequenced behind the binding constraints above.

2.5 Conclusions on barriers to industrial flexibility

A number of barriers to industrial flexibility were identified from literature and complemented with views from the Belgian industry based on interactions with a selection of Belgian companies. These barriers were divided into seven categories, i.e., technological, economic, regulatory, organizational, behavioural, informational and competence-related barriers.

A strong correlation was observed between both the barriers from literature and the barriers faced by the companies. That being said, differences exist in how barriers are perceived. While literature focuses more on macro-level, policy, and market design issues, companies/sectors highlight practical, financial, and operational hurdles they face in real-world implementation of industrial flexibility. To allow for comparison between the different industrial sectors, the sector-specific barriers were linked one on one to the more general barriers.

The sector-specific barriers were described in detail for each company, and it was explained to which level these barriers could be extrapolated to the overall sector-level. These observations were visualised in an overview to allow for a more detailed analysis. A number of observations were made. First of all, certain technological and economic barriers are widely relevant across multiple sectors. Second, regulatory and organizational barriers show sector-dependent contradictions, highlighting the need for tailored policy and corporate strategies. Third, informational and competence barriers vary across industries, suggesting that different sectors require different levels of knowledge support. These insights highlight the need for tailored flexibility strategies based on sector-specific constraints. It is important to explore how companies can mitigate barriers to flexibility through targeted investments, policy interventions, and cross-sector collaboration.

The companies were also asked to prioritize the sector-specific barriers they identified according to impact and time-frame. In this case as well, the sector-specific barriers were linked to the general barriers to allow for a cross-sector comparison. The analysis shows that some general barriers appear across multiple sectors with similar priority levels, suggesting they are universal challenges. At the same time, there are also differences in priority levels across sectors, meaning that some barriers are high priority in one sector but low or medium priority in another.

The analysis also highlights the importance of projects such as GALILEO where insights from scientific literature are extended to applied research at industry-level. Our findings show that some barriers highlighted by the industry as high priority, such as grid-related barriers, were overlooked in literature.

3. Solutions to overcome barriers for industrial flexibility

3.1 Introduction

The potential for flexibility provision is very heterogeneous across industrial sectors and each sector faces unique challenges. Certain sectors exhibit a great potential for flexibility, while other industrial processes are more limited in their ability to provide flexibility due to the non-interruptible nature of the processes, interdependencies, diminishing product qualities, seasonality constraints, etc. Many sectors however face similar challenges, such as uncertain future revenue streams, grid limitations, costly flexibility investments, etc. This chapter directly builds on the critical barriers identified in Chapter 1 and develops a structured overview of solutions to key barriers hindering the uptake of industrial flexibility.

The aim of this chapter is threefold:

1. We compile a range of potential solutions, drawing on desk research and input from industrial partners.
2. We evaluate the performance of each individual solution based on seven key performance indicators that span multiple dimensions and cut across multiple stakeholder groups.
3. By mapping individual solutions to the respective barriers, we quantitatively evaluate the relevance of a solution, both in general as well as within specific industrial sectors.

3.1.1 Methodology

The methodology consists of four main steps aimed at identifying, organizing, and evaluating potential solutions to the key barriers faced by industrial companies.

First, we build on the set of barriers identified in Chapter 2. We retained every barrier deemed critical by at least one industrial partner and removed the non-critical ones. Specifically, we selected all barriers situated in the medium- and high-priority quadrants of Figure 2-19, retaining 57 barriers and removing 21 low-priority ones. The goal at this stage is to ensure that the analysis remains closely aligned with real-world challenges experienced in industrial settings.

The **second** step involves compiling a comprehensive list of potential solutions to the retained barriers. This is done through a combination of desk research and input from the partner companies. The desk research includes a review of existing literature, i.e. peer-reviewed academic research, conference contributions and technical documents on policy and market design analyses. In parallel, we collect input from the partner companies through multiple interviews to capture practical insights, operational constraints, and company-specific experiences. Note that, to the authors' knowledge, there does not exist a review paper that offers a comprehensive and structured review on enablers for industrial flexibility. As such, the overview that will be presented fills a critical research gap by synthesizing both theoretical and practical knowledge on potential enablers for industrial flexibility.

The **third** step involves organising the large number of individual barriers and solutions into broader, more manageable categories. We first establish direct links between each individual barrier and solution. A single solution often addresses multiple barriers, and conversely, an individual barrier may be tackled by several different solutions. We identify these links and, based on this mapping, cluster individual barriers into barrier categories and individual solutions into solution categories. The clustering approach selects clusters such that the number of links between barrier and solution clusters is minimised. As a result, solutions are categorised in clusters that target similar barriers, and barriers are categorized in clusters that can be targeted by similar solutions.

Importantly, this categorisation of barriers differs from that in Chapter 2, where the grouping was based on the origin of barriers, i.e. behavioural, informational, economic, etc. Here, the perspective is shifted by clustering based on the overlap in applicable solutions that address the barriers. In other words, barriers are grouped together not because they stem from a similar source, but because they can be addressed through similar means. This approach enables (i) a more systemic evaluation of the individual solutions by highlighting their relevance across multiple barriers, and (ii) allows to retain a general and accessible overview.

In the **fourth** step, the collected solutions are *qualitatively evaluated*. We first define a set of key performance indicators (KPIs) that span multiple dimensions and form the basis of this assessment. Each solution is then evaluated across the KPIs, using a discrete scoring scale to reflect the solution's expected desirability. In addition, we assign a *quantitative priority score* to capture the practical importance of each solution. The priority analysis is first performed for all sectors in general, and is then further disaggregated through a sector-specific lens. This approach consequently enables to evaluate which solutions are most relevant to specific sectors.

3.1.2 Structure

This chapter is structured as follows. Section 3.2 provides an overview of the solutions identified to overcome barriers to industrial flexibility. Section 3.3 offers more details on the rationale for the clustering procedure. This section also presents the barrier clusters that can be targeted by similar solutions and links the solution categories to these clusters. Section 3.4 evaluates the respective solutions, both qualitatively based on a set of KPIs, and quantitatively to assess their practical importance. Section 3.5 concludes.

3.2 Solutions for industrial flexibility

This section provides an overview of the key solutions for industrial flexibility identified through desk research and input from industrial partners. In total, we have identified 43 solutions, each of which addresses at least one medium-to-high-priority barrier. Table 3-1 presents an overview of these solutions as well as the key references that discuss them. The table furthermore indicates whether a solution was mentioned during the interviews with the industrial partners. Figure 3-1 categorizes these enablers per solution cluster. As discussed in Section 3.1.1, we have grouped individual solutions into clusters to improve readability. We will provide more details on this procedure in Section 3.3; for now, it is sufficient to understand the categories and individual solutions.

Starting with a general description of the seven solution categories:

- **Company-internal levers** (Section 3.2.1) can be implemented within the organization and target internal processes, structures and capabilities. They aim to create the organizational conditions necessary for identifying and activating flexibility potential.
- **Infrastructure investments** (Section 3.2.2) involve upgrading or expanding physical and digital assets. Examples include investments in flexible production equipment, on-site storage, the electricity grids, or advanced metering and IT infrastructure. These solutions often require significant upfront capital but can play an important role in enabling flexibility.
- **Market design** (Section 3.2.3) refers to structural changes to electricity markets that improve ease of access and financial incentives for industrial flexibility providers. This encompasses measures such as adjusting product definitions, improving pricing signals and simplifying participation requirements.
- **Market roles and responsibilities** (Section 3.2.4) involves aligning the roles, rights, and obligations of the various actors in the energy system. This includes model agreements and contractual obligations, as well as coordination synergies. These measures aim to facilitate more seamless participation at lower transaction costs.
- **Information and awareness strategies** (Section 3.2.5) aim at improving the knowledge base and understanding of industrial flexibility among relevant stakeholders. This can involve targeted communication, dissemination of best

practices, or the provision of tools for transparency. These efforts can help companies better understand the value, opportunities, and requirements associated with flexibility.

- **Public support mechanisms** (Section 3.2.6) comprises policy instruments and funding schemes designed to support industrial flexibility or to reduce the associated risk. This includes grants, tax incentives and feasibility studies. Such mechanisms aim to lower upfront costs, de-risk investments, and encourage adoption.
- **Regulatory and legal reform** (Section 3.2.7) involves adapting standards and regulatory frameworks to create a more enabling environment for industrial flexibility. This includes grid tariffication, streamlining permitting processes, and coordinating legal requirements with the provision of flexibility.

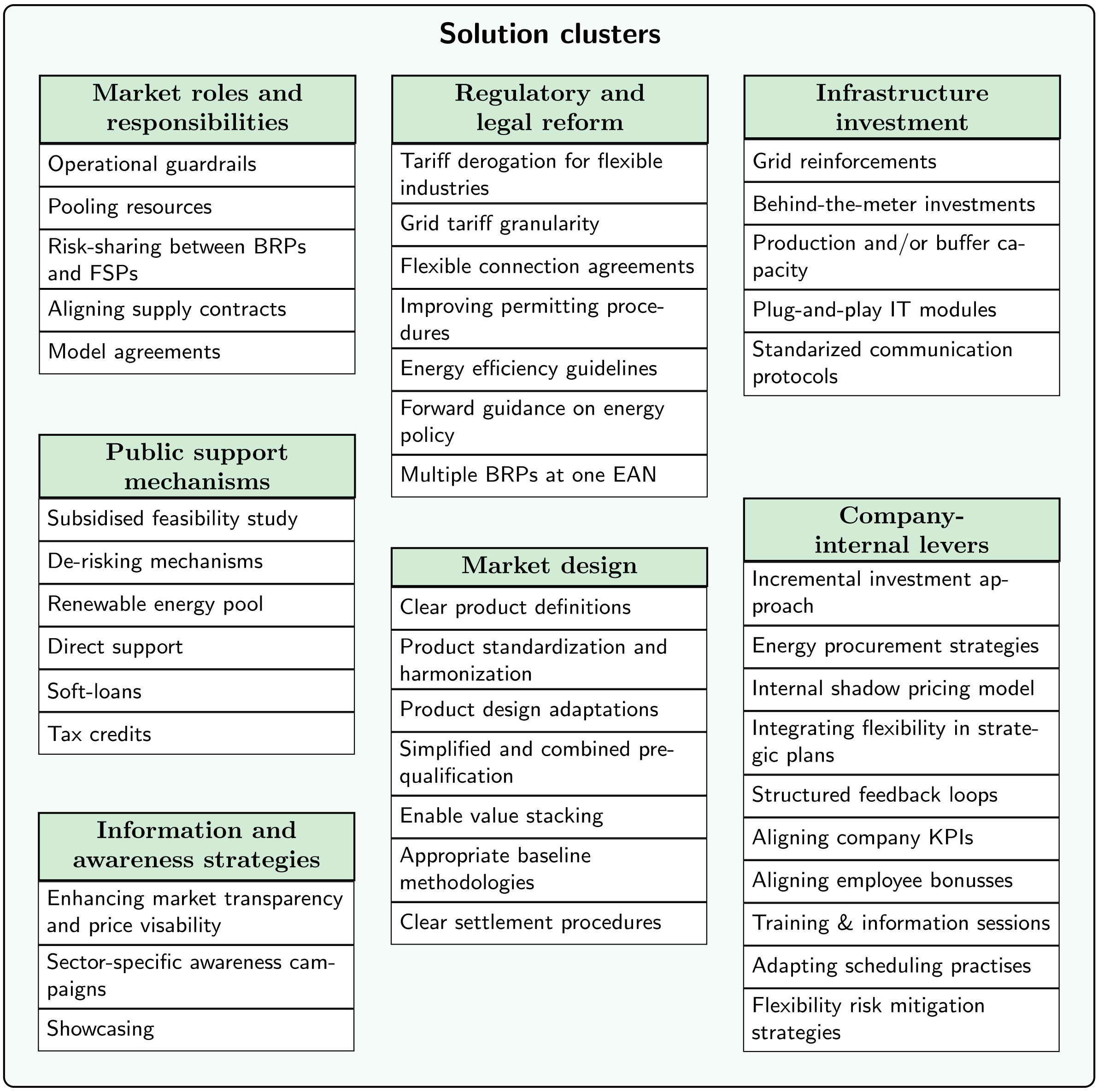

Figure 3-1: Overview of solutions, categorized per solution cluster.

Table 3-1: Overview of solutions along with key references. 'Partner input' indicates that the solution was proposed during the interviews held with the industrial partners.

Company-internal levers	
Integrate flexibility in strategic plans and investment criteria	[128], [129], [130], [131]
Integrate flexibility into internal metrics and KPIs	[128], [132], [133], [134], partner input
Aligning employee remuneration and feedback processes	[43], [135], partner input
Adapt energy procurement strategies	[134], [136], [137], [138], [139], partner input
Internal shadow pricing model for flexibility	[136], [140], [141], [142]
Mitigation strategy for flexibility cost risks	[61], [134], [139], [143]
Incremental investment approach	[134], [136], [141], [144], partner input
Structured feedback loops between impacted departments	[38], partner input
Adapted scheduling practises	[134], [139], [145], [146]
Training sessions and communication	[43], [61], [134], [147], partner input
Infrastructure investments	
Grid reinforcements	[148], [149], [150], [151], partner input
Behind-the-meter investments	[94], [134], [152], [153], [154], [155], [156], partner input
Production and buffer capacity	[61], [146], [157], [158], [159], [160], partner input
Standardized communication protocols for demand response	[43], [71], [93], [132], [147], [161], [162], [163], [164]
Plug-and-play modules for DR market access	[43], [147], [164], [165]
Market design	
Development of clear product definitions	[43], [142], [147], [166], [167], [168], partner input
Product standardization and harmonization	[43], [91], [95], [142], [145], [169], [170]
Product design adaptations	[43], [80], [147], [167], [169], [171], [172], [173], [174], partner input
Simplified and combined prequalification	[146], [175], [176], [177], [178], [179], [180]
Enable value stacking	[175], [181], [182], [183], [184], [185]
Establish appropriate baseline methodologies	[43], [80], [167], [186]
Clear settlement measurement, validation, and procedures	[52], [186], [187], [188], [189]
Market roles and responsibilities	
Pooling resources: joint operation and management of DR	[43], [61], [142], [145], [146], [176], [190], [191], [192], [193], [194], partner input
Risk sharing between BRPs and FSPs	[142], [143], [169], [190], [195], [196], [197], partner input
Operational guardrails: opt-out clauses, maximum activations and minimum notice	[43], [59], [61], [134], [144], [146], [198], [199], [200], [201], partner input
Aligning supply contracts with flexibility participation	[43], [147], [171], [176], [202], [203], [204], partner input
Model agreements and standardised onboarding for flexibility provision	[133], [205], [206], [207]
Information and awareness strategies	
Enhancing market transparency and price visibility	[146], [208], [209], [210], partner input
Showcasing	[54], [144], [176], [211], [212], partner input
Sector-specific awareness campaigns	[112], [144], [176], [211]

Public support mechanisms	
Soft-loans	[43], [54], [213], [214], [215], [216], [217]
Taks credits	[54], [213], [215], [216]
De-risking mechanisms	[43], [170], [218], [219], [220], partner input
Renewable energy pool	[221], [222]
Direct support	[43], [134], [212], [213], [214], [215], [217], partner input
Subsidized feasibility study	[216], [223], [224]
Regulatory and legal reform	
Grid tariff granularity	[59], [147], [171], [176], [225], [226], [227], [228], partner input
Derogations for flexible industries	[59], [60], [229], [230]
Flexible connection agreements	[231], [232], [233], [234], [235], [236], partner input
Energy efficiency guidelines	[54], [144], [237], [238], [239], partner input
Allowing for multiple BRPs at one EAN with submetering	[240], [241], partner input
Streamlining permitting procedures	[149], [204], [242], [243], partner input
Forward guidance on energy policy	[43], [171], [189], [244], [245], partner input

3.2.1 Company-internal solutions

Industrial flexibility does not begin with policy incentives or external market signals, but begins inside the company. This section presents a set of strategies that companies can adopt within their own operations, governance, planning, and culture to actively reduce or overcome barriers to flexibility.

The solutions discussed here span the full internal landscape: from high-level strategy and governance integration to operational planning practices and on-the-ground capacity building. They reflect concrete measures that companies can implement regardless of external policy shifts.

We group company-internal solutions into four clusters:

1. **Strategic and governance integration**: Embedding flexibility into strategic planning, investment criteria, internal KPIs, and leadership roles.
2. **Enabling financial logic**: Aligning procurement strategies with market signals and improving internal economic valuation of flexibility.
3. **Feasibility and investment readiness**: Using stepwise investment approaches, feasibility assessments, and cross-departmental coordination to support flexibility projects.
4. **Operational integration**: Adapting scheduling, enabling real-time responsiveness to flexibility signals, strengthening internal capabilities, building trust in and reducing resistance against flexible operation through training and inclusive engagement.

Together, these strategies aim to shift flexibility from being a theoretical possibility to becoming an integrated part of daily operations and long-term decision-making.

3.2.1.1 Integrate flexibility into strategic plans and investment criteria

Industrial flexibility is often approached as a technical or operational adjustment rather than as a structural component of long-term business strategy. To move beyond this limited view, companies should **integrate flexibility explicitly into their strategic plans and investment criteria**. This means recognizing flexibility not only as a way to reduce energy costs or respond to price volatility, but also as a contributor to broader objectives such as decarbonization, operational resilience, and risk management.

Integrating flexibility into strategic frameworks helps to create internal legitimacy. When flexibility is included in corporate energy transition plans, multi-year investment roadmaps, or sustainability strategies, it becomes a recognized field for action rather than an optional add-on. This change enables internal teams to frame flexibility projects not merely in terms of direct returns, but also in terms of their contribution to long-term strategic objectives. For instance, companies may begin to accept longer payback periods for projects that enhance grid interaction capabilities, or they may start to assess the value of avoided regulatory risk, improved customer reputation, or enhanced energy system resilience. In some cases, internal investment decision rules can be adjusted to allow flexibility projects to compete more fairly with efficiency projects or asset upgrades.

Nevertheless, the integration of flexibility into strategy documents is not sufficient in itself. There is a risk that flexibility is mentioned symbolically without any operational follow-through. To avoid this, strategic recognition must be supported by clear responsibilities, budget allocations, and internal processes that ensure flexibility is translated into action. Without these, flexibility remains marginal in practice, even if formally acknowledged in corporate documents.

3.2.1.2 Integrate flexibility into internal metrics and KPIs

Even when flexibility is acknowledged in strategy documents or decarbonization plans, it often remains disconnected from the internal metrics that guide operational priorities and performance evaluation. Without **inclusion in key performance indicators (KPIs) or internal monitoring frameworks**, flexibility projects struggle to gain traction. In practice, departments and managers focus on what is measured and rewarded. If flexibility does not count towards performance targets, it is unlikely to be prioritized in planning, staffing, or budget decisions.

To overcome this barrier, companies can begin by developing internal flexibility readiness indicators. These do not require active market participation but help track and assess internal progress. Such indicators might include the share of assets controllable through automation or the ability to respond to a flexibility activation within a defined timeframe. These metrics create a baseline from which to build and improve internal capabilities.

In a more advanced stage, flexibility can be incorporated directly into operational KPIs. For example, an energy manager’s objectives might include the identification of new flexibility use cases or the delivery of flexibility services. At the level of plant management, KPIs could be expanded to account for avoided peak loads or participation in grid services, where relevant. This formal recognition supports cross-departmental alignment and ensures that flexibility becomes part of regular operational planning, rather than a peripheral concern.

However, care must be taken to design these metrics in a way that reflects the specific context of each site or process. Rigid KPI frameworks may lead to unintended consequences if, for example, flexibility is pursued at the expense of product quality or long-term efficiency. Effective implementation therefore requires co-design between energy, production, and finance teams, as well as transparent communication about the rationale and value of these new indicators.

3.2.1.3 Aligning employee remuneration and feedback processes

Aligning remuneration and feedback processes with flexibility objectives helps to close the gap between strategic ambition and operational reality. For industrial flexibility to be effectively embedded, it must be supported by the daily decisions and actions of employees involved in production, energy management, and technical oversight. When those responsible for implementation perceive flexibility as a source of risk, disruption, or additional effort with no corresponding recognition or reward, resistance is inevitable. One important lever to address this issue lies in aligning flexibility efforts with remuneration systems and internal feedback mechanisms. Addressing this requires more than just technical training or raising awareness; it calls for a review of individual and team performance evaluations and rewards in relation to flexibility.

Several approaches can be taken. One option is to **broaden the set of performance indicators** used in staff evaluations to include contribution to flexibility-related activities. In parallel, **qualitative feedback mechanisms** such as regular debriefings, structured feedback loops, or recognition during team meetings can help to validate employee efforts and reduce resistance.

In all cases, it is important that such changes are introduced in a **transparent and inclusive manner**. Staff must understand the rationale for flexibility, how their role fits into the wider objectives, and how changes to the reward system will affect them. Flexibility should not be positioned as an additional burden, but as a shared effort that is valued by the organization.

3.2.1.4 Adapt energy procurement strategies

Energy procurement strategies play a decisive role in enabling or constraining industrial flexibility, even when flexibility is not valorised through price arbitrage or spot market exposure. Whether flexibility is offered through grid balancing services, such as aFRR or mFRR, or for other purposes, the underlying procurement approach determines the degree of operational freedom, financial risk, and coordination between departments. When procurement contracts are rigid, centralized, or misaligned with site-level operations, they can discourage or even penalize flexibility activation — regardless of its technical feasibility or market value.

Adapting energy procurement strategies does not necessarily imply full exposure to wholesale price volatility. Instead, it is about designing procurement frameworks that create operational room for flexibility, avoid unnecessary penalties, and align with the company's flexibility ambitions. This can take various forms. Companies may renegotiate supplier contracts to include tolerance margins for load deviations, introduce more dynamic volume allocations between sites, or implement internal mechanisms to reallocate surplus volumes when actual consumption diverges from forecasted levels (e.g. multi-site re-allocation).

In addition, energy procurement strategies can also contribute directly to strengthening the business case for flexibility by enabling the stacking of multiple value streams. When flexible load shifting is both technically feasible and supported by the organization, companies may opt to procure a portion of their electricity through dynamic pricing arrangements, such as day-ahead market or imbalance exposure or supply contracts with time-variable rates. While such exposure is not strictly necessary for participating in flexibility products, it can enhance the overall financial return of a flexibility strategy. For example, a site offering reserve capacity in aFRR or mFRR may also be able to reduce energy procurement costs by shifting consumption to lower-priced hours in the day-ahead market. In such cases, the combination of energy cost optimization and reserve market remuneration can significantly improve project economics.

3.2.1.5 Implement internal shadow pricing models for flexibility

Estimating the financial value of flexibility is essential for building credible internal business cases. **Shadow pricing models allow companies to simulate the financial impact of providing flexibility services** without needing to engage in real-time markets. These models provide indicative values for flexibility, based on assumptions about market prices, avoided costs, and operational constraints. While not intended as precise forecasts, they offer a structured way to assess the potential benefits and trade-offs of flexible operation.

Shadow pricing exercises offer a pragmatic way to address uncertainty. For example, a company might simulate how shifting a drying or cooling process to a different time window could have affected procurement costs under a day-ahead pricing scenario. Alternatively, internal data on process behaviour could be used to model the theoretical income from participation in flexibility markets. These simulations can also be expanded to include cost factors, such as the effect on grid tariffs, capacity charges, or CO_2 allowances. By incorporating these parameters, the models not only estimate potential revenues but also highlight operational risks (e.g. production loss and efficiency deterioration) and constraints that would affect real-world performance.

The development of such models requires a good understanding of the relevant market conditions, flexibility products and technical processes. For many companies, this can appear complex or resource-intensive. However, external support can assist in building tailored shadow pricing tools that reflect the specific characteristics of a company's processes, load profiles, and market context. While the results may not capture every detail with absolute precision: they enable flexibility to be quantified, compared, and assessed alongside more conventional investment options, rather than remaining an insufficiently defined or speculative concept.

By embedding shadow pricing into early-stage project assessments, companies can develop a more mature and risk-aware perspective on flexibility. This strengthens the internal investment case for flexibility investments and helps to build familiarity with the economic dynamics of demand-side participation.

3.2.1.6 Implement mitigation strategy for flexibility cost risks

Participating in flexibility markets not only generates potential revenues, but also introduces new types of cost exposure. These can include increased and more uncertain grid charges, imbalance charges, penalties for non-delivery, or unforeseen operational impacts on energy procurement arrangements. To protect the business case for flexibility, companies should consider developing internal strategies to anticipate, monitor, and mitigate associated cost risks.

Even well-designed flexibility projects can become financially unattractive if cost risks are not properly managed. Implementing a mitigation strategy begins with identifying which risks are relevant for the site or asset in question. This includes understanding how flexibility actions interact with grid tariff structures (e.g. peak charging, injection charges), supply contracts (e.g. maximum deviations from contracted volumes, exposure to variable prices, exposure to imbalance settlement), and market participation obligations (e.g. response times, delivery accuracy). Once these are mapped, mitigation measures can be developed to reduce the likelihood or impact of negative outcomes.

For instance, grid tariff risks can be mitigated by adjusting activation thresholds to avoid triggering new load peaks, or by using internal buffering (e.g. storage or process decoupling) to spread consumption changes over time. Imbalance risks may be reduced through contractual aggregation with third parties who offer portfolio balancing services. In cases where forecast deviation is a barrier, contracts can be renegotiated to include tolerance margins, or internal planning processes can be refined to better align expected consumption with flexible operation.

A potential pitfall is to assume that flexibility is always financially beneficial. In practice, even small deviations from expected activation patterns or activation rules (e.g. non-delivery penalties) can introduce disproportionate costs. Without dedicated attention to the risk side of the equation, companies may find themselves exposed to financial penalties or increased production costs, outcomes that can discredit flexibility internally and lead to reputational resistance.

By proactively identifying and addressing the cost risks associated with flexibility provision, companies can protect their financial interests and reinforce the credibility of flexibility as a viable part of their energy strategy.

3.2.1.7 Incremental investment approach

For many industrial companies, the **capital expenditure** required to enable flexibility remains a key barrier to implementation. When flexibility projects require large upfront investments in automation, infrastructure upgrades, or new equipment, they often face internal competition from more familiar or immediately profitable projects. To overcome this issue, companies can adopt an incremental investment approach, in which flexibility is built up gradually through smaller, lower-risk steps. This staged strategy allows companies to test assumptions, spread cost over time, and generate early insights before committing to full-scale deployment.

An incremental approach helps reduce these barriers by framing flexibility as a process of capability development rather than a single all-or-nothing investment. For example, a company could start by automating a limited number of high-impact loads or piloting manual demand response in non-critical processes. If successful, these early efforts can be expanded with confidence and internal learning. Over time, the company can develop a deeper understanding of its flexibility potential, reduce technical uncertainties, and adjust its planning based on observed performance and market developments. Importantly, this approach also allows time to align supporting elements such as procurement strategies, internal KPIs, and risk mitigation measures.

Incremental investments can also be structured to leverage external support mechanisms. By identifying modular or low-cost upgrades that align with public subsidy schemes or pilot funding programs, companies can reduce their capital expenditure contribution while still building meaningful capability. In some cases, third-party service providers or aggregators may be willing to co-invest in exchange for a share of future flexibility revenues, further reducing upfront capital requirements.

3.2.1.8 Create structured feedback loops between impacted departments

Effective flexibility implementation relies not only on technical capability or strategic ambition, but also on continuous learning across the organization. Structured feedback loops between departments impacted by flexibility initiatives are essential to identify bottlenecks, address practical challenges, and adapt internal processes over time. These loops help ensure that lessons from pilots, operational disruptions, or evolving market participation are captured and translated into improvements in planning, design, and decision-making.

Creating structured feedback loops means going beyond informal communication or occasional consultation. It involves establishing recurring exchanges, either through dedicated meetings, shared documentation systems, or cross-functional working groups, where teams such as production, energy management, maintenance, and procurement can exchange insights about the functioning of flexibility measures. These interactions allow for early detection of unintended side effects, such as reduced equipment availability, inefficiencies in coordination, or misaligned incentives.

A well-functioning feedback loop also supports a culture of iterative improvement. When operators and other frontline staff have a formal channel to report observations or concerns, they are more likely to engage constructively with flexibility measures. Their experience can inform adjustments to control strategies, scheduling algorithms, or communication protocols. Moreover, feeding this information back to strategic levels allows organizations to fine-tune investment priorities or revisit internal KPIs in light of real-world experience.

In more mature setups, feedback loops can be supported by digital tools that track performance indicators, activation events, or deviations in energy use, and visualize them across departments. However, the most important feature remains the organizational discipline to listen, reflect, and adapt. Without a mechanism for this, friction between departments often persists, and flexibility fails to become embedded in day-to-day operations.

By establishing structured and recurring exchanges across departments, companies can make flexibility implementation more robust, reduce internal friction, and gradually build an organizational environment where flexibility is integrated into normal operational dialogue.

3.2.1.9 Adapted scheduling practises

For many industrial companies, **scheduling** lies at the heart of operational control. It defines when processes run, which teams are active, and how inputs and outputs are balanced across time. Yet in most cases, **production scheduling is designed to optimize throughput, resource efficiency, or delivery reliability**, without accounting for the potential value of energy flexibility. To enable meaningful flexibility, companies need to adapt scheduling practices so that they can respond to energy market signals or grid needs without compromising production stability or internal coordination.

Adapted scheduling does not necessarily mean full adaptation to real-time price volatility. It can take more pragmatic forms, such as creating scheduling windows that allow for variation within a defined range, integrating flexibility constraints into planning software, or assigning shift leaders the authority to activate flexibility within operational limits. In some cases, this may involve using forecasted day-ahead prices or balancing market signals as additional input factors in the planning process. Where production processes are highly interconnected, changes to scheduling must be tested for their impact on quality, flow, and resource availability (material and personnel). Over time, however, companies can build a library of operating conditions under which flexibility is possible, and use this to guide scheduling decisions.

Another aspect of flexible scheduling is the coordination between energy and production planning teams. These functions are separated in many organizations and energy considerations only enter the picture after the production schedule has been fixed. Bridging this gap requires new routines. In certain cases, flexibility can be embedded into maintenance planning as well, for instance, by scheduling downtime during periods of high energy system stress or high energy market prices.

A potential pitfall is that too much scheduling freedom creates operational instability, such as frequent rescheduling or increased workload for planning teams. This may generate resistance and reduce trust in the system. The solution is to frame flexibility as an input to scheduling, not as an overriding goal, but as a parameter that helps optimize performance within broader business objectives.

3.2.1.10 Training sessions and communication

Developing industrial flexibility is not only a question of technology or capital investment; it also requires internal understanding, shared language, and behavioural readiness. Many of the barriers encountered in the GALILEO project, such as operator resistance, lack of awareness among decision-makers, or scepticism towards automation, stemmed not from the technical infeasibility of flexibility, but from uncertainty, discomfort, or unfamiliarity with flexibility. **Targeted training sessions and structured communication efforts** can help to bridge these gaps and ensure that flexibility becomes a recognized and supported element of day-to-day operations.

Training efforts should be tailored to the different audiences within a company. For operators and technical staff, this means focusing on the practical impact of flexibility on equipment behaviour, quality standards, and troubleshooting procedures. For planners and shift coordinators, the emphasis may lie on how flexibility can be integrated into existing routines without compromising delivery or safety. For senior management, training should highlight the strategic relevance of flexibility, its role in decarbonization and risk mitigation, and the conditions under which it adds financial value. Importantly, training should not only cover what flexibility is, but also what it is not: it is not equivalent to production cuts, and it need not conflict with core operational objectives when properly managed.

Communication plays a complementary role. In the absence of clear internal narratives, flexibility can be misinterpreted as a distraction or a risk. Regular internal updates, visual dashboards, or short debriefs after pilot projects can help build transparency and normalize the discussion. Companies may also benefit from showcasing successful interventions—no matter how small—to illustrate that flexibility is achievable and controllable.

A key risk is to treat training as a one-off exercise. Knowledge around flexibility is often fragmented and evolving. New staff join, market conditions change, and regulations shift. Building flexibility literacy requires repeated engagement and ongoing communication, rather than a single intervention. Without this continuity, initial awareness may fade, and internal scepticism may re-emerge when future projects are proposed.

3.2.2 Infrastructure solutions

Realising industrial flexibility at scale necessitates the availability and adequacy of support infrastructure. Physical and digital assets must be in place to enable flexible operation and communication with other market parties. This includes both external infrastructure, such as the electricity grid, as well as on-site systems, such as flexible production units, thermal or electrical storage, and buffer capacity. Equally important is the digital infrastructure required to interface with system operators and market platforms, such as data exchange protocols and standardized market access modules. In what follows, we discuss each of these elements in turn.

3.2.2.1 Grid reinforcements

Grid limitations have become a significant challenge, with many industrial grid users facing queues for new connections or reinforcements or are facing non-firm grid access [233]. Several industrial partners flagged limited hosting capacity as a barrier to further electrification or flexibility provision. Grid reinforcements are the obvious long-term solution to address this challenge. It directly increases hosting capacity and facilitates the integration of new loads. These upgrades will take time and are currently constrained by supply chain limitations[6] and permitting procedures.

One potential solution is for transmission and distribution system operators to prioritise reinforcements that enable connection of electrical loads with a sizable flexibility potential. The drawback is that this will deprioritise investment in other grid areas, and it will be up to the system operator to effectively manage these trade-offs. The currently pressing grid access limitation cannot be addressed by infrastructure upgrades alone and requires complementary short-term measures, as will be discussed in Section 3.2.7.3.

Finally, it’s worth noting that industrial flexibility itself can help alleviate grid constraints. If properly integrated into congestion management mechanisms, i.e. redispatch systems or flexibility markets, flexibility can reduce local grid stress, increase hosting capacity and defer the need for grid investment.

3.2.2.2 Behind-the-meter investments

Industrial sites may be technically unable to provide flexibility due to **limitations in on-site electrical infrastructure**. Production processes may furthermore lack sufficient ramping ability, or electrical constraints such as voltage and reactive power limitations may prevent them from being utilised. As a result, otherwise promising flexibility options may remain unexplored without targeted on-site upgrades.

Behind-the-meter investments are investments in electrical infrastructure such as battery storage or power electronics. Several industrial partners highlighted that investment in power electronics is potentially required to maintain power quality during flexibility events to safeguard equipment or comply with the grid code. Electrical battery capacity, on the other hand, can serve several purposes. They can be used to participate in electricity and ancillary

[6] The European Grid Package (expected Q1 2026) may provide some relief [204].

service markets, independently from the production process, even though their value is potentially greater when integrated with flexible operations. Batteries could for example increase self-consumption of on-site renewable generation by storing excess production, using it during peak consumption events, and consequently saving on energy and potentially network costs. Batteries can also support industrial processes in providing flexibility, for instance by charging or discharging to help meet market response requirements when the underlying process itself cannot adjust sufficiently fast. Note that these solutions do require significant capital investments as well as control mechanisms, and their economic viability is best assessed on a case-by-case basis. Still, these behind-the-meter investments can substantially enhance the technical and economic potential of industrial sites to provide flexibility.

3.2.2.3 Production and buffer capacity

A common barrier to industrial flexibility is the **tight coupling between production steps**. Offering flexibility in an upstream part of the process can jeopardize the continuity of downstream operations. Indeed, temporarily pausing an input process to reduce load may leave subsequent units without feedstock. A different issue is that many industrial sites operate their production lines at or near full capacity to meet output targets. This leaves little room to upwardly adjust operations and to offer downward flexibility. **Investments in buffer and production capacity** can help address these challenges.

Buffer capacity refers to intermediate storage such that process stages can be decoupled to an extent. This is not feasible for all processes because, for instance, intermediate products are not allowed to cool down. Production overcapacity, on the other hand, enables processes to operate below their nominal maximum under normal conditions, creating a margin to ramp up as needed. Both solutions can unlock flexibility, but, as with behind-the-meter infrastructure, are capital intensive and must be assessed carefully. The sizing or buffers or additional production capacity is not trivial and requires careful analysis of the business case, the process dynamics and the expected duration of flexibility activations. Where justified, however, these mechanisms offer a robust approach to introduce flexibility without compromising production reliability and output targets.

3.2.2.4 Standardized communication protocols for demand response

Another frequently cited barrier to industrial participation relates to the **high IT effort and complexity involved in integrating with external software platforms**. Many flexibility schemes require secure data exchange and real-time communication with system operators or aggregators. For industrial companies, these requirements can be technically burdensome and resource-intensive. The lack of standardized protocols leads to custom, case-by-case integrations that are difficult to scale or replicate across multiple sites.

The **introduction of standardized communication protocols** can substantially lower these barriers. By using interoperable formats for dispatch signals, baseline reporting, and verification, these protocols can significantly reduce integration and transaction costs. This not only lowers the threshold for initial participation but also supports long-term scalability and reduces dependence on proprietary systems. It furthermore allows incorporating uniform security features and reduces the burden on individual firms to safeguard their data across the systems.

There is a risk that standardisation efforts follow a one-size-fits-all approach that overlooks the operational diversity of industrial sites, resulting in protocols that are too rigid to meet industrial needs. To avoid this, standardization should be a coordinated effort across several actors, i.e. system operators, technology providers, aggregators, industry bodies and regulatory authorities. While its implementation requires significant upfront effort and investment, standardization does hold the potential to accelerate industrial participation in demand response.

3.2.2.5 Plug-and-play modules for DR market access

Plug-and-play IT modules for demand response (DR) market access provide a second option to address the complexity and resource demands involved in setting up IT systems. Plug-and-play IT modules offer a practical solution by providing configured software and hardware packages designed specifically for DR market participation. These models simplify the technical onboarding process and require minimal customization. While integration with specific industrial process still requires effort, these solutions serve to reduce the overall implementation burden. On the other hand, reliance on pre-built modules could risk vendor lock-in or limit customization for highly specialized processes.

3.2.3 Market design solutions

Electricity market design plays a pivotal role in integrating flexible resources from industry. All potential market segments which can be targeted by industry are considered, covering; wholesale electricity markets, ancillary services, imbalance settlement, congestion management products for TSO and DSO, and capacity remuneration mechanisms.

1. **Wholesale electricity markets** facilitate the trading of electricity. Especially the day-ahead and intraday markets are important platforms for valorising flexible electricity consumption and/or production, e.g. by optimising the production and consumption profiles or by arbitrating between energy prices or between multiple energy carriers.
2. **Ancillary services** help maintain grid stability and operational security. Flexible resources can provide these services to the TSO in return for a relatively stable and predictable source of revenue.
3. **Imbalance settlement** provides a financial incentive to balancing responsible parties (BRPs) to stick to their day-ahead nominations. Industrial players can use flexible capacity to avoid excessive penalties or even generate additional revenues by reacting correctly to the imbalance price signals.
4. **Congestion management services** address local network congestion by coordinating injections and withdrawals of electricity. Like ancillary services, these can provide a stable and predictable source of revenue.
5. The **Capacity Remuneration Mechanism (CRM)** provides incentives for the availability of generation capacity and demand-side resources during periods of high system stress. They remunerate potential capital expenditures required by industrial players to unlock (long-duration) flexibility.

To enable market parties to effectively bid into the aforementioned flexibility markets/mechanisms, the right products need to be defined for each of these services. In addition, it is important to cover the different market phases. Four distinct phases can be distinguished: Prequalification, Procurement, Activation and Settlement.

Adapting the electricity market product design and processes can be done by changing its design attributes. The main electricity market design attributes can be divided into product characteristics, pricing mechanisms, and trading arrangements:

1. **Product characteristics**
    a. Minimum bid size
    b. Energy and capacity requirements
    c. Delivery or activation duration
    d. Activation direction (upward/downward)
    e. Frequency of activations
    f. Notification time
    g. Symmetry requirements
    h. Ramp rate requirements
    i. Geographical restrictions

j. Technology restrictions
k. Aggregation rules
l. Divisibility

2. **Pricing mechanisms**
   a. Availability vs activation remuneration
   b. Market clearing mechanisms
   c. Settlement frequency
   d. Price caps and floors
   e. Penalty schemes
   f. Baseline definition
3. **Trading arrangements**
   a. Gate closure time
   b. Trading period
   c. Trading horizon
   d. Prequalification arrangements

3.2.3.1 Development of clear product definitions

To ensure that industrial flexibility can effectively participate in electricity markets, **products must be defined in a way that is understandable, accessible, and practically implementable** by a broad range of actors. Clear product definitions are a prerequisite for transparency, comparability, and investment confidence. They reduce the transaction costs of market participation and ensure that potential contributors, including industrial consumers, can assess ex ante whether their flexibility matches the system need.

To avoid ambiguity, product development should begin with a clear definition of the product. Flexibility products should be defined in a technology-neutral way, ensuring that all technically capable resources can contribute. This requires early consultation with potential FSPs and industrial actors to incorporate their operational constraints and capabilities into the product design.

As the same flexibility providers could potentially offer several products, it is important to avoid too many different and non-comparable products. For these services it is thus important to consider existing products and assess whether the product definition could start from the existing ones. Specifically, for these products covering local needs, there are some new requirements for the product definition.

For system services where no clear European product definitions currently exist, such as congestion management or reactive power support, it is important to assess whether existing products can serve as a starting point. At the same time, excessive fragmentation into overlapping or non-comparable products should be avoided, particularly in contexts where aggregation across sites or technologies is required.

Congestion management products, in particular, can take multiple forms, each with distinct implications for industrial participation. One approach is implicit capacity allocation, where locational information is incorporated into flexibility bids submitted to existing markets, such as the balancing or day-ahead market. During market clearing, the grid impact of each bid is evaluated, which may result in the selection or rejection of bids based not only on price, but also on their ability to relieve or avoid congestion. This method can preserve liquidity in the main market, but requires standardization in how locational data is communicated, especially in aggregated bids that pool flexibility from different sites.

A second model is market-based redispatch, as implemented for example through GOPACS in the Netherlands. In this setup, the system operator procures upward or downward adjustments in real time or intraday to relieve congestion, selecting offers that are both technically suitable and cost-efficient.

A third option is the development of a dedicated congestion market, in which local flexibility needs are addressed through a specific market product. This can take the form of a central auction or continuous trading platform, where buyers and sellers of congestion services interact based on clearly defined criteria. Such a market enables competitive procurement tailored to the specific characteristics of local grid constraints and allows industrial providers to access a new revenue stream.

3.2.3.2 Product standardization and harmonization

A commonly agreed approach to product definition and specification is lacking across Europe, particularly for flexibility services beyond balancing. While frequency-related ancillary services benefit from standardization initiatives like PICASSO, MARI and TERRE, other services, such as congestion management or voltage control, are often defined on a national or even regional basis, leading to inconsistency in design and terminology. This fragmentation complicates market participation for industrial actors, especially those operating across multiple grid areas or collaborating beyond country borders.

A first level of product standardization could consist of a product template that defines common attributes across all services. These attributes, such as activation lead time, minimum bid size, activation duration, and remuneration structure, should be described using consistent terminology and units. This approach leaves room for national or regional implementations to define values appropriate to local grid needs, without undermining interoperability or increasing the administrative burden for market participants.

For DSOs, who typically operate in more context-specific environments, a less rigid standardization approach may be more appropriate. However, even here, harmonizing terminology and structure can reduce entry barriers (e.g. for companies with multiple sites in different DSO networks). The use of a shared framework, combined with transparent documentation and publishing of product parameters, would already be a significant step forward.

In summary, to avoid discrimination among market parties or technologies, categories of products should be defined according to a commonly agreed template for all services but allowing national/regional implementation to select adapted values for certain attributes where relevant. Specific attention should be given to avoid very diverse products or the introduction of too many different products, while still leaving enough room to consider local specificities. The need for local specificities is typically important for DSO flexibility services and might demand tailored product definitions to match particular locational circumstances.

3.2.3.3 Product design adaptations

In addition to the need for clear product definitions and harmonized frameworks, **specific adaptations to product design characteristics can significantly improve the accessibility** of electricity market products for industrial flexibility providers. Many industrial processes face physical, operational, or organizational limitations that make it difficult to comply with rigid product specifications. By adjusting key product attributes, market operators and regulators can lower entry barriers, enabling a broader set of industrial actors to contribute.

A concrete example concerns ramp rate requirements. These requirements define how fast a flexibility provider must increase or decrease its power consumption or injection following activation. High ramp rate requirements can be prohibitive for many industrial facilities that cannot modify load instantaneously due to process constraints or safety procedures. Reducing ramp rate requirements or introducing a tiered remuneration system that compensates slower but still valuable responses, could broaden access to ancillary services and improve overall system participation.

Another design element with major implications is not only contract duration but also the energy-duration requirement in capacity mechanisms. In Belgium’s CRM, new gas-fired capacity can obtain up to 15-year contracts, while industrial demand response typically receives one-year contracts. In addition, DSR is procured as energy-constrained CMUs and is mainly valued for support during short adequacy moments, which rewards brief peak contribution rather than multi-hour delivery. This disadvantages investment-based industrial flexibility that requires CAPEX (for example buffer tanks or “virtual battery” configurations). A balanced reform would combine medium-term contract options for investment-based DSR (for example three to five years) with duration-aware remuneration. This would provide greater revenue certainty, reduce investment risk, and level the playing field between demand-side and supply-side capacity while aligning incentives with system reliability needs over both short and long scarcity episodes.

Finally, risk-adjusted penalty design is crucial for industrial participation. Many industrial stakeholders report that current penalty structures for non-delivery are excessively harsh or binary, discouraging them from entering the market altogether. Introducing more nuanced penalty schemes, such as graded penalties based on deviation size, grace margins for first-time participants, or variable penalty profiles based on reliability history, would make participation more attractive. Such adjustments can help industrial players price and manage their risk more accurately and reduce the perceived financial downside of engaging with flexibility markets.

Together, these targeted product design improvements could reduce access barriers and improve the business case for industrial flexibility.

3.2.3.4 Simplified and combined prequalification

Current prequalification processes for flexibility provision are often complex, time-consuming, and fragmented, creating a substantial barrier to entry. Procedures have typically been designed for central, utility-scale units, and are not well adapted to decentralized or aggregated industrial flexibility. Industrial actors face challenges in navigating multiple procedures across services (e.g. frequency containment, frequency restoration, and congestion management) and buyers (TSOs and DSOs). In Belgium, separate prequalification tracks exist for different ancillary services, implying a duplication of effort and limited scalability.

To improve accessibility and efficiency, prequalification could be made simpler, more standardized, and better aligned across services and system operators. Two concrete recommendations are (i) introducing standardized prequalification procedures for multiple services wherever possible, and (ii) allowing prequalification at the aggregated pool level. Standardized prequalification measures would imply applying a uniform set of criteria and processes for multiple services, wherever technically feasible. This could include a common data submission process, shared testing procedures, or mutual recognition of technical validations across services and system operators. For instance, once a unit is prequalified for one ancillary service, it should be easier or automatic to extend that qualification to others (provided technical compatibility is confirmed).

Allowing prequalification at the aggregated pool level would verify whether a portfolio of assets, rather than each individual one, can collectively meet product requirements. A separate grid prequalification would then verify whether the network can handle activations. Note that in the longer term, grid prequalification could be replaced for certain products if grid constraints are well integrated in procurement or activation platforms.

While simplification holds value, the quality or reliability of flexibility services should not be compromised. The objective is to have a user-friendly and scalable system that maintains technical standards while reducing entry barriers. Indeed, flexible assets are still required to reliably respond within required timeframes and to deliver contracted volumes. Process changes should hence focus on eliminating duplication and manual effort rather than lowering service level expectations.

3.2.3.5 Enable value stacking

One of the most frequently mentioned barriers to industrial flexibility is that revenues from the provided services are often insufficient to justify the required investment and internal effort. Value stacking refers to the ability to simultaneously participate in multiple flexibility markets and can enhance the business case of industrial demand response. A more integrated and coordinated market design would allow industrial actors to unlock the full value of their flexibility potential while support system efficiency.

A first step could be to ensure that timing and product design across flexibility services are aligned. More fundamental though, would be to move to a more coordinated approach to producing flexibility. Currently, market participants have to decide for themselves how to divide their flexibility among products, based on price expectations and technical constraints. An alternative would be that the transmission system operator allows the submission of a single bid across multiple services and implements a joint clearing mechanism that is only able to accept this bid once, wherever it brings the highest system value. Such a coordinated clearing would not only simplify participation but also ensure effective allocation of flexibility. Over time, such mechanisms could be expanded to include flexibility services requested by both TSOs and DSOs for congestion management purposes.

Moving towards a coordinated approach is not without challenges. Many flexibility products (e.g. technical characteristics, gate closure times) are harmonized at the European level. Any changes to procurement would likely require broader regulatory adjustments. Additionally, capacity products for balancing purposes are cleared sequentially. For example, gate closure of FCR occurs before that of aFRR, and that of aFRR before that of mFRR. This setup allows market participants to reallocate unaccepted bids to subsequent markets, probably without an efficiency loss as the prices within these subsequent markets are likely lower due to less demanding response requirements.

The added value of a coordinated flexibility service procurement approach instead becomes evident when integrating additional services such as congestion management (on TSO and DSO level), which typically operate on different timelines. How to properly coordinate all these mechanisms remains an open question and warrants further research.

A final opportunity lies in the facilitation of a secondary market for reserve capacity. Such a market would increase both liquidity and reliability of the ancillary services framework. It would provide industrial participants with a safety net by allowing them to transfer their reserve obligations in case they are unable to deliver (for instance due to unforeseen outages). This would lower the perceived risk of non-compliance and enable more conservative actors to enter the market. Vice versa, (industrial) flexibility that requires shorter lead times (e.g. due to scheduling practices) can sell their services on these secondary markets.

3.2.3.6 Establish appropriate baseline methodologies for flexibility services

For many flexibility services, financial remuneration and performance evaluation depend on the difference between the actual offtake profile and a baseline, i.e. an estimate of what offtake would have been in the absence of activation. **Establishing fair and robust baseline methodologies** is hence important, but it also presents some key design challenges. Indeed, inappropriate methodologies can distort incentives, create gaming opportunities.

For FSPs that already submit individual schedules to the system operators (e.g. CIPU units), no additional mechanism is needed as their individual schedule would serve that purpose. For other providers, it is recommended to develop a structured categorisation of best practices, along with a methodology for selecting and validating baseline approaches. These baselines should strike a careful balance between accuracy, transparency, data requirements, and robustness against manipulation.

In early phases of development, it might be desirable to allow FSPs the free choice of a baseline methodology, in consultation with the service requester. This approach, already used for aFRR services in Belgium, enables portfolios to use the method most suited to their consumption patterns and operational constraints. As experience accumulates, these custom methods could form the basis for more standardised baseline categories. This could hence be seen as an intermediary measure, to allow for innovation and to test and develop new approaches. In some cases, self-declared baselines may be sufficient, particularly for non-critical services, although these would typically require validation mechanisms to prevent abuse. Over time, harmonisation of baseline principles and methodologies, i.e. across similar services and within a European context, could reduce complexity for cross-border FSPs and aggregators.

3.2.3.7 Establish clear measurement, validation and settlement procedures, taking into account harmonization efforts

Reliable settlement procedures are essential to ensure trust in flexibility markets. Once a flexibility service has been delivered, the amount of flexibility must be accurately measured, validated, and remunerated. For industrial actors, especially those participating through aggregators or in complex setups, the clarity and fairness of these settlement processes are critical to determining whether participation is desirable.

Measurement, validation, and settlement procedures are generally defined at the national level and reflect country-specific data flows and regulatory frameworks. Greater harmonization at the European level is needed to support the cross-border exchange of services and lower market entry barriers for aggregators and FSPs operating in multiple countries.

An important consideration is the role of submetering, particularly for industrial sites with multiple processes or tenants behind a single grid connection. In addition, aggregation models must ensure both accurate settlement and verifiable delivery at the grid user level. This is particularly relevant in industrial contexts where assets may contribute partially or variably to an activation signal. Transparent, coordinated, and standardized settlement frameworks that balance accuracy with simplicity are ultimately necessary to build confidence and scale up participation in flexibility markets.

3.2.4 Market roles and responsibilities

Industrial flexibility unfolds through a network of market actors, each with distinct roles, responsibilities, and commercial interests. The effectiveness of industrial demand response therefore depends not only on the internal readiness of a company, but also on the contractual and organizational frameworks that shape how flexibility is activated, remunerated, and governed across parties. These frameworks include the relationships between industrial sites and aggregators or flexibility service providers (FSPs), balancing responsible parties (BRPs), electricity suppliers, and, in many cases, parent companies or site operators with shared infrastructure.

Findings from the GALILEO project revealed that these relationships are often characterized by uncertainty, fragmentation, or misalignment. In several cases, companies expressed confusion over who holds delivery responsibility in case of non-performance: the aggregator, the BRP, or the industrial provider itself. In other instances, supply contracts penalized deviations from pre-agreed volumes, effectively disincentivizing flexible operation. Even when flexibility was technically and economically feasible, unresolved questions around liability, imbalance risk, or activation control created a barrier to participation. These concerns are particularly acute in settings where production is sensitive to disruption, or where internal processes are already complex.

In many cases, the lack of standardized contractual structures or prequalification templates places a disproportionate burden on first-time participants, especially smaller industrial actors. Conversely, companies with experience in the market reported that the key to success lies in clear agreements that define activation rights, risk-sharing arrangements, communication procedures, and fallback conditions.

This section presents a set of solutions aimed at improving the contractual and organizational architecture of industrial flexibility.

3.2.4.1 Pooling resources: joint operation and management of DR

Industrial flexibility is often technically available in partial, fragmented forms. Industrial companies often perceive flexibility participation as a high-risk or high-complexity endeavour.

This is particularly true when it comes to navigating market procedures, ensuring performance across all activations, or managing the administrative burden of direct participation. **Pooling mechanisms—where multiple sites or actors collaborate to jointly provide demand response—offer a way to mitigate these risks.** By sharing operational responsibility, commercial exposure, and transactional costs, pooling allows companies to enter flexibility markets with less individual risk while still contributing to system-level needs. This approach is particularly attractive for companies with limited internal resources, uncertain availability of flexible loads, or a preference to avoid direct engagement with balancing markets.

Pooling can take several forms. The most common involves industrial sites working with an aggregator or an FSP who consolidates the flexibility potential of multiple clients into a single market-facing portfolio. This joint operation allows the aggregator to optimise dispatch across sites, smoothen variability, and meet the technical and commercial requirements of balancing or capacity markets. For the industrial participant, this model lowers the entry barrier by externalising prequalification, forecasting, and bid submission, while still providing access to flexibility revenue streams. The aggregator may also offer compensation models that reduce exposure to non-delivery penalties, making the proposition more attractive to risk-averse operators.

Beyond the typical aggregator-client model, pooling may also occur between industrial sites within the same company group or business park. For example, in a chemical cluster or multi-tenant industrial site, companies may coordinate flexibility provision through shared infrastructure, such as a central energy management system, closed distribution grid, or virtual power plant setup. In such configurations, joint scheduling, metering, and data integration can enable the cluster as a whole to act as a flexibility provider, even if individual participants lack the critical mass to do so alone.

The benefits of pooling extend beyond size aggregation. Industrial participants can share investment costs (for example, for metering upgrades, local control systems, or third-party service contracts) and jointly address barriers such as qualification procedures, data requirements, or reporting obligations. In some cases, a lead party or central energy coordinator may take on administrative or contractual responsibilities on behalf of the group, reducing the burden on individual sites.

However, effective pooling requires clear governance arrangements. Participants must agree on how revenues are shared, how responsibilities are distributed in case of non-performance, and how decisions are made on activation timing. Trust, transparency, and contractual clarity are essential to avoid disputes and ensure long-term viability. Without these, the risk of coordination failure can outweigh the benefits of aggregation.

3.2.4.2 Risk sharing between BRPs and FSPs

Industrial companies are often reluctant to engage in flexibility markets because of the perceived imbalance between risk and reward. In many current arrangements, flexibility providers carry a significant share of the operational and financial risks associated with non-delivery, while receiving only limited control over activation timing or the market participation strategy to be followed. This is particularly problematic in sectors where production is sensitive to interruption, or where internal planning processes cannot easily accommodate short-notice activations. **Risk-sharing contracts between flexibility providers, BRPs, and FSPs** can help to rebalance this relationship, clarify responsibilities, and support more equitable participation in flexibility markets.

Across the GALILEO project, several companies voiced concern about the contractual consequences of being unable to deliver flexibility when called upon. In the food sector, for instance, the refinery was hesitant to commit to reserved load participation due to the risk of penalties in the event of operational disruption. These concerns were amplified by the fact that many companies lacked in-house legal or regulatory expertise to assess risk exposure in complex multi-party contracts. As a result, even technically viable projects were not pursued due to the uncertainty surrounding delivery obligations and financial consequences.

Risk-sharing contracts aim to distribute this uncertainty more evenly between the involved actors. One common approach is to introduce graded penalties or performance bands that reflect partial delivery, rather than applying full penalties for any deviation. Another mechanism involves establishing fallback procedures, such as allowing manual overrides, advance cancellation rights, or substitutions with other assets in the aggregator's portfolio. Some contracts also include financial hedging instruments, such as pre-agreed tolerance margins or imbalance cost caps, that protect the industrial provider against extreme price movements or unforeseen system conditions. In cases where the BRP is not the same entity as the aggregator, tripartite agreements can help clarify roles, liabilities, and escalation procedures.

Risk-sharing also extends to sharing communication and forecasting responsibilities. For example, some aggregators take responsibility for real-time data monitoring, forecasting errors, or communication failures, while others explicitly require the industrial company to maintain forecasting accuracy within a defined margin. Contracts can also specify which actor carries the legal and financial risk in the event of network constraints, service unavailability, or incorrect dispatch signals from market operators.

To be effective, risk-sharing contracts must be transparent, proportionate, and enforceable. Companies need sufficient time and internal capacity to understand terms, test scenarios, and negotiate adaptations where needed. This need is greater for first-time participants, smaller industrial actors, and firms whose legal or risk functions sit centrally at group level. Centralisation typically lengthens timelines because the group team serves many business units, works through a formal queue, and runs multi-stage approvals that span legal, risk, compliance, tax, and sometimes board sign-off, often across jurisdictions. Group policies also restrict deviations from standard clauses, which increases redlining cycles.

While no contract can eliminate all uncertainty, well-structured risk-sharing agreements create a more balanced and predictable basis for flexibility participation. They reduce the fear of unforeseen penalties, increase internal trust in the viability of flexibility business models, and foster longer-term collaboration between industrial sites, BRPs, and FSPs.

3.2.4.3 Operational guardrails: Opt-out clauses, maximum activations and minimum notice

Companies will only provide flexibility services if they retain sufficient control over when and how their processes are affected. For many industrial actors, particularly those with tightly integrated production lines or quality-sensitive operations, the fear of losing operational sovereignty is a key barrier to participation. To address this, flexibility contracts should include clear operational guardrails, i.e. pre-agreed conditions that limit when flexibility can be activated, how often, and with how much advance warning. These guardrails offer a critical bridge between system needs and production realities, enabling trust-based participation.

This concern was raised repeatedly by companies consulted within the GALILEO project. In the food sector, the sugar refinery highlighted the risks of flexibility activation clashing with planned process steps or labour schedules, and pointed to the absence of procedures to reallocate staff or reschedule production on short notice. Similarly, in the chemical and steel sectors, internal teams warned of the strain placed on operators and planning staff by unanticipated activations, especially when these required ramping that conflicted with technical ramp limits or voltage constraints. In these contexts, flexibility participation was seen as potentially destabilising unless strict boundary conditions could be established contractually.

Operational guardrails can take several forms. One common approach is the inclusion of opt-out clauses, which allow the industrial participant to refuse activation under predefined conditions, such as planned maintenance, exceptional load levels, or ongoing production bottlenecks. These clauses can be configured as automatic exemptions or ad hoc veto rights, depending on the technical setup and trust between parties.

Another form of guardrail is the specification of a maximum number of activations within a given timeframe (e.g. per day or per month), which provides predictability for staffing, maintenance planning, and process efficiency.

Related to this is the concept of minimum notification periods, whereby the company is given a guaranteed lead time (for instance 30 minutes, two hours, or one day) before activation occurs. This ensures that flexibility can be coordinated with internal schedules and supervisory structures.

In more advanced setups, operational guardrails can be embedded digitally, through dispatch filters or integration with production planning systems. These filters ensure that activations are only sent when internal conditions are suitable, based on real-time process data or predefined thresholds. However, contractual clarity remains essential, particularly when industrial actors rely on third parties, such as aggregators or BRPs, to interface with the market. Guardrails must be enforceable, transparent, and well understood by all parties involved.

A potential risk is that overly restrictive guardrails reduce the usability of flexibility for market actors or system operators. If too many opt-out conditions are allowed, or if notice periods are incompatible with market lead times, the flexibility may become commercially unviable. To avoid this, guardrails should be calibrated based on actual process needs and regularly reviewed as operational experience accumulates. In some cases, industrial actors may be willing to gradually reduce restrictions as confidence grows, and internal procedures mature.

3.2.4.4 Aligning supply contracts with flexibility participation

In several cases observed during the GALILEO project, supply contracts proved to be a hidden barrier to flexibility: rigid volume commitments, inflexible pricing structures, or contract penalties for deviations from nominations discouraged companies from engaging in even modest levels of load shifting. Where flexibility participation implies deviating from forecasted consumption, traditional supply arrangements can become a source of conflict rather than an enabler.

This issue was particularly visible in companies where electricity procurement was managed centrally or externally, such as through a parent company or corporate trading desk. In the food sector, for instance, the sugar refinery highlighted that deviations from monthly forecasts had to be compensated through market resales, often at a financial loss. In such a setup, even if flexibility participation generated value on one side, such as through remuneration from balancing services, it could simultaneously incur costs elsewhere in the organisation, eroding or eliminating the net benefit. The result was that local teams, despite having technical options for flexibility, were constrained by contractual rules beyond their control.

To unlock flexibility in such environments, electricity supply contracts need to be adapted to recognise and accommodate flexible consumption behaviour. One approach is to introduce tolerance bands into contractual volume commitments, allowing limited upward or downward deviation without triggering penalties. This provides industrial sites with the room to respond to market signals or grid requests while maintaining commercial alignment with their supplier or internal procurement unit. Another option is to embed flexibility clauses into supply agreements, specifying how load shifts will be treated, how imbalance costs are handled, and whether participation in demand response programmes is permitted under the terms of the contract.

In more integrated models, flexibility provision is coordinated directly between the supplier and the industrial customer. For example, the supplier may act as both BRP and FSP, offering a bundled product that includes electricity supply and demand-side participation. In such cases, contract structures can be designed to facilitate activation, prequalify assets, or monetise flexibility through shared savings models. These arrangements can be particularly effective for companies with limited internal capacity to engage with multiple market actors, as they consolidate responsibilities and reduce transaction complexity.

3.2.4.5 Model agreements and standardised onboarding for flexibility participation

For many industrial companies, the complexity and uncertainty of entering into contractual arrangements with FSPs, BRPs, or suppliers can form a substantial barrier. This is particularly true for companies new to flexibility markets. Negotiating terms around activation rights, data exchange, delivery obligations, and risk allocation requires legal and technical expertise that is not always available in-house. In the absence of standardised templates or onboarding frameworks, each engagement becomes a bespoke process, time-consuming, resource-intensive, and often opaque. As a result, smaller or less experienced companies are disproportionately excluded from market participation, even when they possess the technical capacity to offer flexibility.

This challenge was evident across several cases in the GALILEO project. Companies reported difficulty in assessing the implications of aggregator contracts, understanding their rights in case of non-delivery, or determining how flexibility participation would interact with existing supply agreements. Some companies expressed frustration at the lack of accessible reference material or contractual benchmarks. Without clear guidance or standardised starting points, internal decision-making slowed and uncertainty prevailed, particularly where legal or procurement departments had little prior exposure to demand-side contracting.

Introducing model agreements and standardised onboarding procedures can significantly lower these entry barriers. These templates can take the form of pre-drafted contracts or modular clauses covering the most common flexibility arrangements, such as revenue sharing models, opt-out procedures, fallback conditions, and data privacy provisions. They can be adapted to different regulatory contexts and market roles, for example, between an industrial provider and an FSP, between a supplier and a BRP, or within corporate groups managing flexibility across multiple sites.

In some cases, market actors themselves may take the lead in providing these templates. FSPs or suppliers can support client onboarding by offering legally vetted frameworks that reduce negotiation effort and clarify expectations. Alternatively, regulatory bodies or industry associations can develop reference contracts or contractual toolkits, ensuring consistency and fairness while maintaining enough flexibility to reflect sectoral or regional differences.

Standardised onboarding also extends beyond contracts. Clear documentation, qualification guidelines, and procedural roadmaps can help companies understand the steps required to participate, the obligations involved, and the criteria for remuneration. This is particularly important in balancing markets or capacity schemes where prequalification is complex or product definitions are evolving.

3.2.5 Information and awareness

A lack of information and awareness remains a significant, and potentially underestimated, barrier to industrial flexibility. Not all companies are aware of their flexibility potential or familiar with the mechanisms through which flexibility can be monetised. Even when the technical potential exists, internal resistance (e.g. from plant managers, operational staff or senior management) can hinder progress. Addressing these issues requires not just technical solutions or financial incentives, but also targeted information and communication efforts. In what follows, this section outlines and details three complementary strategies: improving market transparency and visibility on the value of flexibility, supporting showcasing, and launching sector-specific awareness campaigns.

3.2.5.1 Enhancing market transparency and visibility on the value of flexibility through objective comparison tools

Industrial participation in flexibility markets depends not only on the attractiveness of aggregator offers but also on the clarity of products issued by system operators. In practice, many firms find the business case opaque because the value proposition is unclear and the contractual path is complex. Service descriptions sit within extensive technical and contractual documentation, and flexibility participations are often communicated in fragmented, highly technical formats. For risk-averse industries where energy is not a core activity, this lack of clear, user-friendly product summaries, standardised term sheets, and worked settlement examples slows internal decision-making and frequently results in non-participation.

During the GALILEO project, several companies reported difficulty in assessing the costs and benefits of proposed aggregator arrangements. Offerings varied widely in structure, terminology, and underlying assumptions — making it hard to understand expected revenues, operational impact, or contractual liabilities. This lack of transparency disproportionately affects smaller or less experienced companies, who may not have internal expertise to interpret or compare such proposals.

To address this, market actors (and/or public authorities) could support the development of objective, user-friendly tools that help industrial consumers evaluate the offerings of aggregators. These tools could present key contract parameters, such as availability and activation requirements, historical revenue estimates, penalty schemes, or data obligations, in a standardized format. By enabling structured comparisons across multiple providers, they would empower grid users to make informed choices aligned with their operational profiles and risk tolerance. By increasing market transparency and the comparability of aggregator offerings, these tools and practices would support fairer competition, lower market entry thresholds for industrial players, and ultimately contribute to a more liquid market.

3.2.5.2 Showcasing

Industrial flexibility is still a relatively new concept in many sectors, and companies are often hesitant to act without seeing concrete, real-world examples of successful implementations.

Several industrial partners of the GALILEO project have highlighted that convincing internal stakeholders is a key barrier. The chemical sector, for instance, mentioned difficulties in getting plant managers to recognize the value of offering flexibility, while the food sector pointed to challenges in convincing higher management to prioritize flexibility alongside other strategic objectives.

Showcasing pilot projects or case studies can help demonstrate the technical and financial viability of flexibility projects. Seeing how other firms, particularly within the same sector, have implemented flexibility without compromising operations, can trigger interest and reduce perceived risk and scepticism. Internally, companies could potentially draw upon examples at other sites within the same company to convince plant management. More generally, public actors can play a role by coordinating demonstration projects and disseminating results through sector-specific channels. It is a relatively low-cost measure that can effectively communicate best practices and encourage companies or plants to explore flexibility solutions.

3.2.5.3 Sector-specific awareness campaigns

An industrial player's unawareness of its flexibility potential can be addressed further through awareness campaigns. **Generic information campaigns** can serve as a useful starting point by highlighting the value of flexibility and potentially providing case-by-case examples. Then again, flexibility solutions are typically sector- and process-specific, and broadly targeted campaigns do not convey the operational realities of individual industries. As a result, companies may, perhaps mistakenly, believe that their operational processes cannot accommodate demand-side response.

Sector-specific awareness campaigns provide a solution as they can tailor content to the specific characteristics of each sector. Sector federations are particularly well positioned to take up this role, given their sector-specific knowledge and communication channels. They can address sector- and process-specific concerns and can help dispel misconceptions and encourage firms to explore flexibility opportunities that may otherwise be overlooked. These campaigns offer a targeted and low-cost measure that can spark a firm's interest by concretely communicating potential flexibility solutions to explore.

3.2.6 Public support mechanisms

Public support mechanisms can play a critical role in enabling demand response by overcoming financial and investment barriers. They can specifically alleviate barriers that relate to inadequate (or uncertain) revenues and that relate to high upfront (and risky) investments. Targeted market interventions could furthermore be considered to enhance the overall competitiveness of the industry or specific sectors. These mechanisms additionally benefit from the recent European electricity market reform [220], which states that Member States could consider the promotion of non-fossil flexibility like demand response or storage. If capacity mechanisms are not sufficient to meet national flexibility targets, flexibility support schemes can be introduced.

In what follows, we provide an overview of several options, which are not necessary mutually exclusive. The appropriateness of the different options generally depends on the market failure(s) that policymakers are trying to address. For example, revenue uncertainty is a common problem in electricity markets. In the case of renewable electricity producers, most Member States address revenue uncertainty through state-backed derisking schemes, typically contracts-for-differences. Direct subsidies could also be justified to compensate for market inefficiencies that artificially discriminate against demand response.

The design of public support mechanisms needs to be carefully considered. Some subsidy mechanisms may introduce undesirable side effects, such as distorting operational decisions and/or efficient price formation. There is also a risk of subsidizing facilities that have a low system value for flexibility. Public support mechanisms can be valuable in unlocking industrial flexibility, but their exact design characteristics warrant further research.

3.2.6.1 Soft loans

Multiple industrial partners raised lack of access to (affordable) capital as a key barrier to investing in industrial demand response measures. Similarly, and perhaps more indirectly, several companies were faced with the inability or unwillingness from management to divert capital towards non-core projects with uncertain and long payback periods. Soft loans could play a part in addressing these barriers. They can help unlock projects that would otherwise be delayed or deprioritized. This is particularly relevant for industrial actors with limited internal financing capacity or restricted access to commercial credit (at competitive rates).

Soft loans are financing instruments provided at preferential interest rates and can feature longer repayment terms or partial guarantees. These terms are specifically designed to lower the upfront financial burden and reduce the risk perceived by lenders of investing in new flexibility measures. Soft loans are typically backed or even funded by public institutions and are often tied to specific eligibility criteria (e.g. load-shifting capabilities).

3.2.6.2 Tax credits

Tax credits are a widely used policy instrument to stimulate private investment in areas deemed to have societal value. In the context of industrial flexibility, they can help increase profitability by reducing the net cost of demand response investments. Well-designed tax credits can be targeted to specific flexibility outcomes, such as improved responsiveness to market signals or verifiable peak load reduction.

Tax credits work by lowering future tax liabilities. This makes them relatively more attractive for governments, as grants or soft loans require upfront cash transfers or public lending mechanisms. Tax credits also have limitations: they are less immediately valuable to companies with no or limited taxable income, such as companies recovering from downturns or companies in capital-intensive sectors operating on slim net margins. In such cases, the credits may not provide additional flexibility incentives. This could be (partially) mitigated by including provisions for refundability, or by combining them with other instruments (such as the previously discussed soft loans).

3.2.6.3 De-risking mechanisms

De-risking mechanisms are designed to **provide (minimum) revenue guarantees** and can hence alleviate revenue uncertainty barriers. These instruments are relatively complex to design and carry the risk of distorting market outcomes, for instance by affecting operational incentives. A well-known example is the Contract-for-Difference (CfD), which shields electricity producers and/or consumers from volatile electricity prices by paying the difference between a predetermined strike price and a market reference price, for each unit of produced/consumed electricity.

In the context of industrial flexibility, designing these mechanisms remains a subject of ongoing research. First, it remains debated how to optimally design a de-risking mechanism for renewable electricity or electrification assets (e.g. e-boilers under the "klimaatsprong" initiative), even though the topic has benefited from intensive research. Second, it is unclear how to translate these mechanisms to industrial flexibility applications, as there are some fundamental differences with traditional CfDs. Unlike generation, where standard CfDs hedge price on volumetric output, demand response revenues are bi-modal: capacity availability (€/MW) and activation energy (€/MWh) that occur at uncertain times and with uncertain frequency. Effective schemes therefore need to address volume risk (number, duration and timing of activations) in addition to price risk.

Another crucial design question for de-risking mechanisms is the contract duration. While CfDs for renewable electricity typically span at least a decade, there is ample evidence that large industrial energy consumers generally prefer shorter contract durations (e.g. 5 years or less). Several authors have observed that large energy companies and industrial users take a big risk when they underwrite an energy contract with a long duration, like 15 to 20 years. If their competitors have not locked in their electricity price for the long term, and if short-term electricity prices decrease, their competitiveness suffers. This observation is also in line with the payback expectations of industrial partners and was explicitly mentioned several times by the industrial partners of the GALILEO project. De-risking mechanisms for renewable electricity (e.g. CfDs) therefore cannot be directly translated to industrial flexibility applications, and we recommend further research into their payout structure and appropriate contract duration.

3.2.6.4 Renewable energy pool

Next to de-risking mechanisms, policymakers could consider the option of a **government-backed renewable energy pool** that tenders long-term contracts with new renewable projects and passes the pooled contracts on to consumers [221], [222]. In other words, governments underwrite CfD contracts with renewable electricity producers (as is planned for offshore wind in the Princess Elisabeth zone) and subsequently pass these provisions on to consumers (possibly repackaged as shorter contract durations). For the government, passing on these provisions removes the risk associated with underwriting CfDs (i.e. low electricity prices and high subsidy payouts). For (industrial) consumers, the system provides a hedge against fluctuating electricity prices according to the generation profile of the pool. In effect, high electricity prices are offset by payouts from the renewable pool and vice versa. Note that this pool does leave consumers exposed to the renewable energy production profile, similar to a pay-as-produced PPA. This will have the (desired) effect of incentivizing consumers to hedge their remaining profile risk by investing in flexibility measures. Buying into this renewable energy pool will consequently increase the value of industrial flexibility and will reduce revenue uncertainty, albeit to a lesser extent than dedicated de-risking mechanisms.

3.2.6.5 Direct support

Direct support mechanisms can serve as targeted interventions to address market inefficiencies that hinder the uptake of industrial demand response. Direct support instruments encompass a range of options, including production-based subsidies (e.g. a payment per activation), capacity payments (e.g. a payment per installed MW of flexible capacity), and investment grants. Each of these instrument entails different implications for efficient incentives, risk, and administrative complexity.

For industrial demand response, we recommend prioritizing upfront subsidies that are either linked to installed flexible capacity (so in EUR/MW) or investment costs (so in %, or EUR/EUR). This recommendation is based on three primary considerations. First, support schemes that tie payouts to volumes of delivered flexibility introduce a degree of revenue uncertainty for participating firms. Since activations are imperfectly predictable and often depend on external factors, such output-based schemes may not sufficiently incentivize participation. Second, output-based schemes are notorious for misaligning incentives and causing market distortions. Third, upfront payments help address one of the most prominent barriers to industrial flexibility, i.e. the high upfront capital costs of infrastructure and automation and control systems.

Note, however, that upfront direct support mechanisms are typically not designed for risk mitigation purposes. In other words, they do not directly address uncertainty on future market conditions and the value of flexibility investment. Direct support mechanisms and risk-mitigation instruments hence target fundamentally different needs. The former may be effective in overcoming inadequate revenues and may compensate for existing market failures or an unlevel playing field, whereas the latter can stabilize revenues from flexibility provision. Given the complementarity, policy makers may consider hybrid approaches that combine upfront support with risk-mitigation elements, such as guaranteed availability payments or some form of minimum revenue guarantees (which may very well be part of a general flexibility support framework, see earlier).

3.2.6.6 Subsidized feasibility study

Key barriers to industrial flexibility include limited in-house capacity to evaluate activation patterns and revenue streams, uncertainty on the flexibility capabilities of production processes, the lack of awareness amongst industries, and scepticism from management. Especially for companies without prior experience with demand response, the perceived complexity of flexibility solutions can prevent exploration of opportunities. In these cases, a **subsidized feasibility study** can serve as a soft incentive.

Subsidized feasibility studies involve partial or full public funding for an assessment of a company's flexibility potential. These studies can include a detailed analysis of technical constraints, offtake profiles, and economic viability under different market conditions. They reduce information asymmetry and provide a decision basis for companies that would otherwise be hesitant to act. In addition, simply offering support for such a study can already raise awareness and incentivize companies to contemplate flexibility measures that would not have been considered otherwise. These studies could involve third-party experts which could improve the credibility and internal acceptance of proposed flexibility measures.

Although flexibility studies do not guarantee implementation, they are a relatively low-cost measure for government that lowers the threshold for industry to take first steps towards flexibility. Over time, a broader rollout of such studies may contribute to mainstreaming flexibility thinking within industry.

3.2.7 Regulatory and legal reform

Regulatory and legal frameworks strongly influence the feasibility and attractiveness of industrial flexibility. In many cases, key barriers do not stem from technical limitations, but from misaligned incentives, conflicting regulations, and administrative complexity. Many of the existing rules are still optimized for stable consumption patterns, rather than dynamic and responsive industrial loads. It is important to address these issues to unlock the industrial flexibility potential.

This section outlines several possible reforms, ranging from grid tariff design and connection agreements (the grid tariff granularity, exemptions for flexible industries, flexible connection agreements), to regulatory initiatives (resolving conflicts with energy efficiency obligations, allowing for multiple BRPs at one EAN, streamlining permitting procedures) and forward policy guidance. The aim is to better align current regulatory practices with the opportunities of industrial demand response.

3.2.7.1 Grid tariff granularity

Several industrial partners have raised significant concerns regarding grid access and grid charges. Both are key barriers to the adoption of industrial demand response, and to electrification at large. In what follows, we first provide recommendations on grid charges and then move on to grid access in Section 3.2.7.3.

In Belgium, grid tariffs are capacity-based and hence based on peak power consumption (rather than, e.g. electricity consumption). Such capacity-based charges are sometimes criticised for hindering industrial demand response. Indeed, engaging in demand response is likely to yield variable load profile with higher peak loads, which potentially increases grid charges. Literature therefore regularly refers to capacity-based tariffs as a barrier to industrial demand response.

It is, however, important to remember that capacity-based tariffs serve a purpose: they aim to reduce peak load and facilitate the efficient operation of the electricity grid. They are generally preferred over flat volumetric charges because network costs are driven by coincident peak capacity rather than total kWh; capacity-oriented signals encourage shaving and shifting of maximum demand, which lowers coincident loading, unlocks hosting capacity on existing assets, and defers grid reinforcement investments. The challenge is not whether to use capacity-based charges, but how to design them so they enable flexibility. With naive designs, it is indeed possible that individual peaks do not coincide with (local) congestion events. This can lead to situations where demand response is being discouraged while transport capacity is still available. Such situations are simply inefficient and represent a pure economic loss. One can avoid them by refining capacity-based tariffs, and specifically by making them contingent on time and location. Note also that time- and location-dependent capacity-based grid tariffs align with recommendations published by ACER [225].

Starting with the temporal aspect, **tariffs can be designed to exclude periods of low network load when calculating individual peaks**. The Belgian transmission tariff design already does exactly this [225]:

> ‘Capacity-based charges are set based on both contractual power (PPAD) and measured power. The measured power-based element is set on monthly peak and yearly peak (kW) and applies for the users at the 30-380 kV voltage levels. The annual peak is measured from November to March, during the 17:00-20:00 period from Monday to Friday (except public holidays). The monthly peak is applied the whole year, except during summer off-peak periods, defined as the weekends from 10:00 to 19:00, between April and September.’

The tariff is consequently designed so that increasing offtake at certain moments in time (e.g. weekends in summer) does not (substantially) increase transmission fees. The idea is that transmission capacity during these moments is ample and that providing flexibility should hence not be discouraged.

Similarly, **capacity-based charges can include a spatial element**, i.e. discounts, exemptions or otherwise differentiating connection charges based on the geographical location of the network user. Well-designed locational charges can generally be beneficial for energy systems as they can address local congestion in specific areas, whilst still leaving opportunities for demand response in uncongested areas. Belgian transmission tariffs currently do not differentiate by location.

The national regulating authority and transmission system operator could investigate whether redesigning the temporal and spatial resolution of transmission charges are feasible and beneficial. Additional research is required because (i) grid tariff design constitutes a trade-off that must consider several dimensions (i.e. reflectivity, fairness, cost-recovery, etc.), and (ii) congestion is hard to predict in advance and often changes following network reinforcements or grid reconfigurations, making the locational signals and network charges potentially more volatile. Adapting grid tariffs also takes time, as they have to remain fixed over a four-year period to offer predictability to market participants. Nevertheless, more granular and dynamic grid charges would sharpen cost reflectivity by signalling strongly during locally congested periods and relaxing the signal where headroom exists, avoiding penalties for harmless peaks while pre-emptively dampening growth toward future constraints.

3.2.7.2 Derogations for flexible industries

Grid tariff derogations for flexible industries or companies represent a less disruptive alternative to a complete grid tariff design overhaul. Specifically, one can grant temporary or conditional reductions or derogations in network charges for industrial consumers that can reliably reduce or shift load. Utility-scale battery storage, for instance, already enjoys these types of exemptions in Belgium [229]. Such exemptions can help activate flexibility because market participants do not face conflicting signals from electricity markets and grid tariffs. Then again, this approach may raise fairness concerns, as not all industries have the same technical ability to respond flexibly and may thus not be eligible to benefit. These measures also mute the signal to reduce peaks and can consequently exacerbate congestion issues. Such derogation schemes should hence be carefully scoped, with transparent eligibility and verification criteria, and ideally be treated as a transitional or exceptional measure within a broader flexibility framework.

3.2.7.3 Flexible connection agreements

Recall that several industrial partners have raised grid access as main barrier for offering flexibility and investing in electrification. **Flexible connection agreements** (FCAs) can offer a short-term solution. These agreements allow industrial consumers to connect to the grid under conditions that may include temporary limitations on offtake, e.g. through interruptibility schemes [233], [235]. Several European Member States have already introduced flexible connection agreements and Belgium will soon do as well at the transmission level. At present, hosting capacity is still allocated on a first-come-first-served basis (if possible).

Several industrial partners expressed concerns about the uncertainty surrounding the design and implementation of flexible connection agreements and highlighted this as main barrier for flexibility and electrification projects. In the short-term, the terms and conditions of flexible connection agreements should be clarified as soon as possible, as the current uncertainty surrounding their implementation is delaying industrial investment in electrification and DSR. Large scale consumers require clear guidance on the conditions and restrictions attached to these agreements and are unlikely to consider additional capacity investments without transparency.

It is furthermore important to remark that FCAs only serve specific network users. Colocation data centres, for example, must be able to guarantee availability and cannot tolerate prolonged interruptions to their power supply. More flexible processes, on the other hand, may be able to accommodate temporary power limitations without significant operational disruptions. This brings us to the main issue with FCAs: there is no guarantee that hosting capacity is efficiently allocated. Some firms may have secured uninterruptible hosting agreements in the past, even though they might have little problems with interruptible schemes. Other firms require a guaranteed and stable power supply for which FCAs are just not an option. It would likely be more efficient if FCAs are granted to battery parks or firms that possess flexible processes, rather than on a first-come-first-served basis [233], [235]. The benefits would be at least twofold. First, allocating FCAs to companies with flexible processes could encourage them to expand their flexibility efforts, benefitting the power system at large. Second, uninterruptible hosting capacity can then be allocated to those who genuinely need it, ensuring that electrification and economic growth progresses smoothly.

Summarizing, TSOs could offer FCAs to existing offtakers and offer both flexible and firm connection agreements to new offtakers.

3.2.7.4 Adapt energy efficiency guidelines

The Energy Efficiency Directive (EED) mandates regular energy audits for large enterprises, requiring them to identify and implement cost-effective energy-savings measures [237]. Under recent revisions, free allocation of EU emission allowances is made contingent on implementing these energy-savings measures. If companies do not implement some of these energy-savings measures, they will see their free ETS emission allocation reduced. As a result, EED audits and their associated energy-savings measures carry significant implications for energy-intensive companies.

A growing concern, also voiced by several industrial partners, is that current energy efficiency metrics and audit methodologies may unintentionally discourage flexibility [54]. Many industrial processes are optimized for maximum efficiency under steady, baseload operation. Introducing demand-side flexibility, such as ramping down during peak hour or operating in off-peak periods, can reduce process efficiency and increase energy consumption. As such, flexibility provision may worsen traditional energy performance indicators. **EED audit and reporting methodologies should consequently explicitly recognize and accommodate flexibility measures**. Otherwise, energy efficiency policies and mandated measures may remain a main barrier to scaling industrial flexibility.

3.2.7.5 Allow multiple BRPs at one EAN with submetering

The chemical sector voiced the issue that, in some cases, multiple companies may be connected to the grid through a single offtake point (designated by an EAN). Under the current regulatory framework, however, only one Balance Responsible Party (BRP) can be assigned per EAN [240]. This setup creates significant coordination challenges when a company at a site with one EAN and multiple companies wishes to offer its flexibility. Indeed, all flexibility actions must be aligned and internally compensated among users behind the same EAN, which introduces administrative complexity and mutes market responsiveness.

The solution would be to **allow multiple BRPs per EAN, based on submetering**. In this arrangement, each company behind the shared connection point would be individually metered and assigned to its own BRP, enabling it to follow market signals and participate autonomously in energy and balancing markets. This approach would not only remove a barrier to offering flexibility, but also eliminate the need for internal coordination and compensation schemes. Additionally, grid access charges and tariffs could, in principle, be allocated more fairly. Note, however, that the implementation requires regulatory updates and clear standards for metering and settlement.

3.2.7.6 Streamline permitting procedures

Permitting procedures for investments related to industrial flexibility or electrification, such as on-site renewable generation, grid reinforcements or general flexibility adaptations, remain lengthy, complex and fragmented. Fragmentation arises because approvals are distributed across several authorities (environmental and land-use, fire and safety, waterway or heritage bodies, DSO and TSO), use different documentation and appeal routes, and vary by region (Flanders, Wallonia, Brussels). Both the food- and steel sector voiced their concerns and highlighted that these procedural hurdles can introduce unpredictable delays, increased planning and financial risks, and in some cases project cancellations.

Streamlining permitting procedures could help to reduce these barriers and accelerate the deployment of flexibility-enabling technologies [149]. This could involve establishing clearer timelines, enabling flexible technologies to benefit from a simplified assessment for a number of environmental obligations, or introducing fast-track procedures. Note that a similar approach has been taken on the EU-level to further promote renewable energy, i.e. it was agreed that the planning, construction and operation of renewable plants is presumed to be in the overriding public interest. Consequently, renewable projects nowadays should benefit from simplified permitting procedures. A similar approach could be taken to encourage flexibility-related investments. Note, however, that simplified and fast-track permitting procedures may face public opposition, and hence care should be taken to balance acceleration efforts with transparency and stakeholder engagement.

3.2.7.7 Forward guidance on energy policy

Uncertainty about the future direction of energy policy is a significant barrier to investment in industrial flexibility [245]. Companies are reluctant to commit capital to flexible technologies if there is no clear signal that such efforts will remain valuable or supported in the future. Frequent policy changes, ambiguous regulatory timelines, or conflicting objectives between different levels of government further exacerbate this uncertainty. Particularly the food sector was concerned with long-term policy uncertainty and highlighted it as high-impact barrier.

Providing forward guidance on energy and market policy and regulation can help to reduce this uncertainty. While it is not feasible nor credible to predict detailed commodity prices and flexibility revenues years in advance, it should be possible to communicate consistent and stable expectations on structural energy sector developments, such as the scale and pace of renewable energy deployment or the associated evolution of flexibility needs. Stable policy signals allow companies to better assess the medium- to long-term business case for flexibility and align their investment decisions with the requirements of the energy system. Forward guidance can not eliminate all risks, but it does play a vital coordinating role.

3.3 Linking solutions to barriers

3.3.1 Objective and methodology

This section serves to understand how solutions outlined in Section 3.2 can help address barriers for industrial flexibility outlined in Chapter 2. We first linked each individual solution to the specific barrier(s) it can mitigate.

One-to-many and many-to-one relationships between solutions and barriers exist: (i) A single barrier can often be addressed by multiple solutions. For example, informational barriers, such as ‘uncertainty regarding financial implications’, can be addressed by enhancing market transparency, adaptations to the market design, risk-sharing between BRPs and flexibility providers, derisking mechanisms, etc. (ii) A single solution may simultaneously mitigate several different barriers. The ‘pooling of resources’ solution, for instance, can alleviate several technological concerns, reduces risks related to non-availability, and enables companies to cope with a lack of internal resources or knowledge.

To cope with these interdependencies, we organized solutions and barriers into clusters. This serves two aims: (i) Barriers can be clustered around shared solutions, enabling a solution-oriented approach. (ii) Clustering enhances interpretability by avoiding excessive granularity and enabling identification of overarching solution-barrier patterns. As such, clusters offer a broader understanding of which interventions may be most effective where.

The barrier and solution clusters were constructed using an adapted assignment problem. We developed an optimization model that considers all selected barriers, solutions, and the individual links between them. The model jointly clusters barriers and solutions in a way that minimizes the number of connections between barrier and solution clusters. The model outcome was then lightly finetuned to enhance interpretability. As a result, solutions are categorised in clusters that target similar barriers, and barriers are categorized in clusters that are addressed by similar solutions. This approach differs from that of Chapter 2, where barriers were grouped based on the origin of barriers, i.e. behavioural, informational, economic, etc. Although that approach was quite suitable for the identification of barriers, we now shift the perspective to offer a more solution-oriented view.

Figure 3-1 and Figure 3-2 respectively show the resulting solution and barrier clusters. Indeed, solutions in Section 3.2 were already structured in the clusters obtained from this clustering methodology. In what follows we focus on the barrier clusters and describe their main characteristics. We then investigate the linkages between barrier and solution clusters to evaluate the extent to which (clusters of) solutions can address specific barrier clusters.

Barrier clusters

Technological and operational limitations
- T1: Risk of disruption
- T2: Technically infeasible to reduce peak load
- T3: Risk of lower product quality
- T5-6: High IT requirements and lack of inhouse IT preqequisites
- T8: Seasonal changes in energy profile
- E8: Potential risk on production target values
- I4: Lack of information regarding electric cirtuits

Grid access constraints
- T2.5: Capacity does not yet exist
- T2.6: Existing grid is congested

Complex regulatory and market framework
- R1: Complex regulatory framework
- R2: Restrictive regulatory framework
- I1: Lack of transparancy
- I3.1: Unclear interpretation of legislation
- I3.2: Uncertainty regarding roles and responsibilities

Organisational misalignment
- E7: Cost savings too far in the future
- R6: Prioritisation of energy efficiency
- O1: Additional workload
- O2: Internal guidelines on project duration
- O4: Low priority of top management
- O5: Company KPIs do note consider flexibility
- O7: Relevant decision makers lack decision power
- O8: Many decision makers involved
- O9: Dependence on external service providers
- B1: Lack of acceptance amongst employees
- B2: Lack of acceptance amongst general public
- B3: Skepticism towards automated interfaces
- C1: Lack of (internal) resources
- C2: Employees lack needed skills
- C4: Lack of knowledge about energy markets

Financing and investment constraints
- E4: Costly flexibility investments necessary
- E5: Lack of access to external and internal capital
- R2.3: Lack of sufficient public funding
- I2: Uncertainty regarding financial implications
- I3: Uncertainty about future regulations
- I7: Costly and uncertain project analysis

Inadequate revenues
- E2: Greater economic appeal of alternative measures
- E3: Lack of revenues through the provision of flexibility
- R2: Flexibility product design
- R4: Distortion of market signals
- O6: Power procurement policy

Increased operational expenditures
- T4: Equipment wear
- E6: Additional operating costs
- E9: Necessary hedging against non-availability
- R5: Conflicts with grid fees
- R7: Penalties for unavailabilities

Figure 3-2: Overview of the medium- and high-priority barriers, categorised per barrier cluster.

3.3.2 Barrier clusters

We have defined the following seven barrier clusters, as depicted in Figure 3-2:

1. **Technological and operational limitations**: physical constraints of industrial processes and their supporting infrastructure. This cluster includes disruption risk, technical difficulties to reduce peak load, product quality concerns, IT requirements, seasonality conditions, production-target risk, and lack of electric-circuit information. These barriers are often embedded in the technical and logistical functioning of industrial operations and often require targeted upgrades or operational redesign.
2. **Grid access constraints:** insufficient or frequently congested local grid capacity inhibiting electrification.

3. **Complex regulatory and market framework:** restrictive and complex regulatory framework, lack of market transparency and insufficient clarity in the interpretation of relevant legislation, and unclear and evolving roles and responsibilities of market participants – such as aggregators, system operators, and industrial consumers.
4. **Organisational misalignment:** internal company factors including misaligned incentives, structural limitations like limited internal resources, lack of relevant skills, or restrictive project timelines, fragmented decision-making, lack of clear ownership, and cultural and behavioural issues including scepticism towards automated systems and low general acceptance among employees or the public.
5. **Financing and investment constraints:** financial and economic factors that limit a company's ability and willingness to invest in flexibility. Flexibility measures often require substantial upfront costs and must compete with other internal projects – such as energy efficiency improvements – that typically offer more immediate or certain returns. As a result, flexibility initiatives frequently struggle to secure capital, a challenge further compounded by significant uncertainty regarding their future financial performance.
6. **Inadequate revenues:** economic disincentives that undermine the business case for industrial flexibility. In many cases, alternative measures – such as optimising for self-consumption – are economically more attractive than participating in flexibility markets. Where flexibility is provided, revenues may be insufficient or not well aligned with the actual value of the service due to the market design or distorted price signals. In addition, internal power procurement policies – such as fixed-price contracts or centralised procurement – can weaken the link between market signals and operational decisions.
7. **Increased operational expenditures:** additional costs incurred when providing flexibility. Frequent changes in operating conditions may lead to increased wear and tear on equipment, raising maintenance needs and shortening asset lifetimes. Flexibility activation can result in higher energy consumption outside optimal operating condition and additional labour costs from changes in employee scheduling. Companies also face costs associated with non-availability risks. Finally, existing grid free structures may penalise altered load profiles and particularly excessive peaks.

3.3.3 Linking barriers and solution clusters

The links between barrier and solution clusters help identify which interventions are best suited to address specific types of barriers.

Figure 3-3 summarizes the strongest linkages between barrier and solution clusters. Darker and bolder arrows indicate stronger linkages, where the strength of a linkage corresponds to the relative number of individual solutions in each cluster that address one or more barriers in the respective barrier cluster. Weaker, less frequent connections are omitted but still exist. For example, some specific market design measures – such as lengthening day-ahead lead times or modifying reserve products – can mitigate scheduling conflicts and thus contribute to the 'increased operational expenditures barrier'. These smaller links are not shown in the figure but will be discussed momentarily. Although clustering reduced excessive cross-linkages, many solution categories still contribute to multiple barrier categories and vice versa.

Figure 3-3 provides insights into the alignment between challenges and potential solutions. Certain solution categories are predominantly linked to specific barrier categories. For instance, company-internal levers are primarily suitable for resolving organisational misalignment. Similarly, infrastructure investment solutions are closely associated with alleviating grid access and technological or operational constraints, and have limited direct influence on other barriers. In contrast, other solutions categories have a more distributed impact. For example, market roles and responsibilities contribute meaningfully to three different barrier categories: technological and operational limitations, increased operational expenditures, and organisational misalignment. As such, some solution classes offer relatively targeted interventions, whereas other classes play an enabling role across multiple dimensions.

The figure can also be read in reverse, highlighting which types of solution are most relevant for addressing specific barrier categories. For example, inadequate revenues are mainly addressed through improvements in market design and through public support mechanisms, whereas company-internal levels offer several complementary solutions. Grid access constraints, on the other hand, are best tackled through infrastructure investment along with some selected measures from the regulatory and legal reform cluster. This perspective is valuable for both policymakers and industrial companies, as it provides a basis for identifying the most valuable interventions depending on the prevailing barrier profile within a given industrial context.

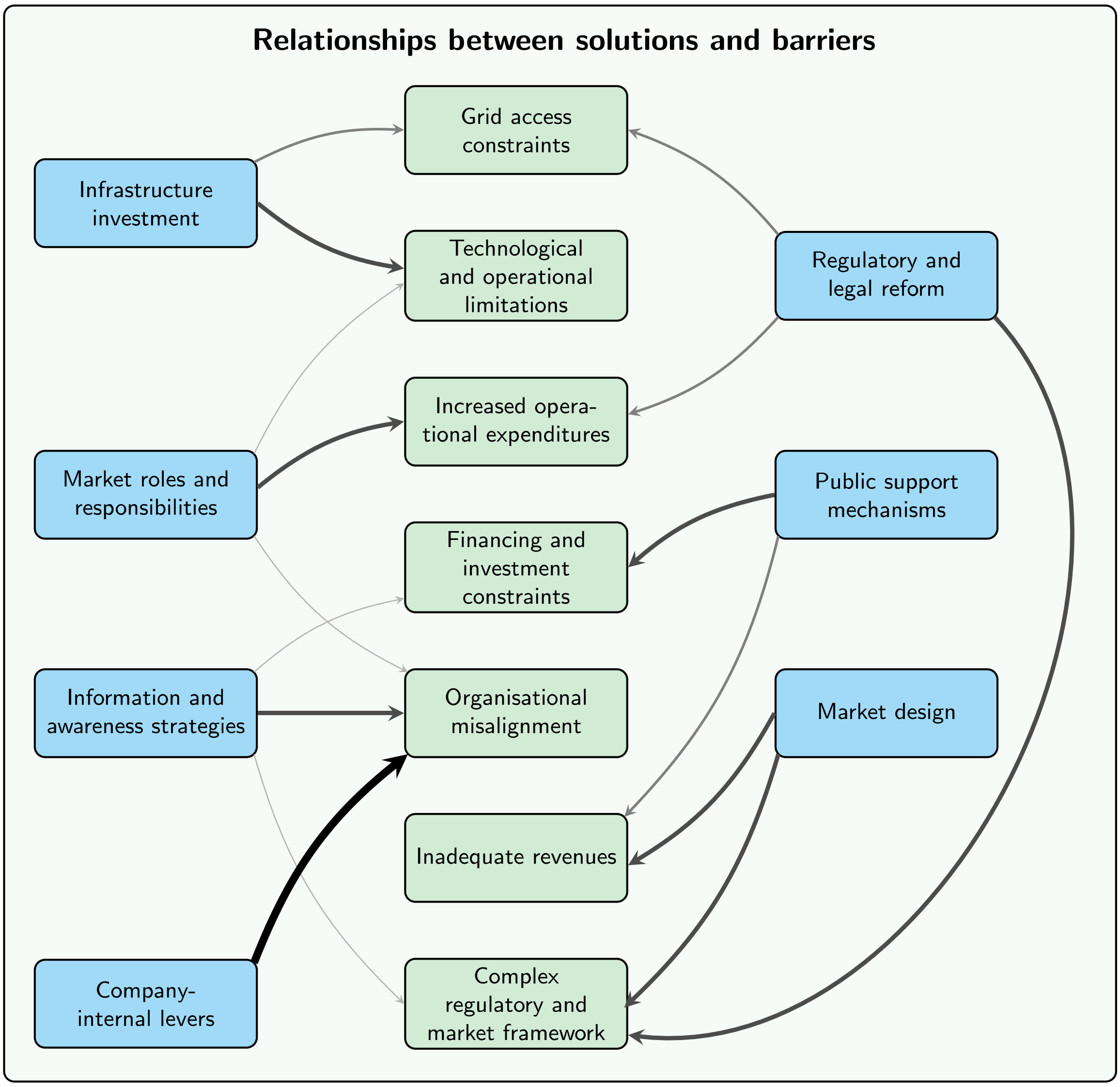

Figure 3-3: Links between barrier and solution clusters. Bolder and darker arrows indicate a stronger link.

The remainder of this section is dedicated to linking individual solutions to the barrier clusters introduced before. Table 3-8 provides an overview which solution can contribute to which barrier cluster. The left column lists the solution clusters, while the right column presents the corresponding individual solutions.

Technological and operational limitations can mainly be addressed by infrastructure investments and changes to the market design. Investments in behind-the-meter technologies and production or buffer capacities enhance the technical capability to offer flexibility, while plug-and-play IT modules and standardised communication protocols enable better data handling, interoperability and automation. Changes to market design can unlock flexibility by reducing ramping requirements in reserve markets or by modifying the clearing schedule and block duration. A longer day-ahead lead time furthermore supports planning and avoids risks for process disruptions. Resource pooling and operational guardrails mitigate risks related to product quality and jeopardising upstream or downstream processes. A subsidised feasibility study, finally, can help identify and assess the technical limits within which a firm can operate and offer flexibility.

Table 3-2: Overview of which specific solutions address technological and operational limitations

Technological and operational limitations	
Solution cluster	Specific solution
Infrastructure investment	Behind-the-meter investments
Infrastructure investment	Production and/or buffer capacity
Infrastructure investment	Plug-and-play IT modules
Infrastructure investment	Standardized communication protocols
Market design	Simplified and combined prequalification
Market design	Product design adaptations
Market roles and responsibilities	Pooling resources
Market roles and responsibilities	Operational guardrails
Public support mechanisms	Subsidised feasibility study
Company-internal levers	Adapted scheduling practices
Company-internal levers	Structured feedback loops

Grid access restrictions can be partly mitigated by infrastructure investments, regulatory and legal reforms and market design changes. Grid reinforcements are the most direct solution but typically involve long lead times. Flexible connection agreements offer a complementary measure that can provide relieve in the short to medium term. Likewise, companies could invest in behind-the-meter technologies (e.g. batteries) to reduce their required connection capacity. From a market perspective, congestion products could help to better integrate flexibility into the congestion management process, thereby supporting more efficient use of existing infrastructure. Likewise, location-dependent grid signals could stimulate projects to select sites with ample grid capacity, at least on the long-term.

Table 3-3: Overview of which specific solutions address grid access

Grid access	
Solution cluster	Specific solution
Infrastructure investment	Grid reinforcements
Infrastructure investment	Behind-the-meter investments
Market design	Product standardization and harmonization
Regulatory and legal reform	Grid tariff granularity
Regulatory and legal reform	Flexible connection agreements

The **complex regulatory and market framework** is best addressed through two targeted solution clusters: (i) product and market design, and (ii) permitting and administrative streamlining. The first cluster covers enabling multiple BRPs per EAN and harmonised aggregator–BRP reconciliation, plus market-design tweaks that align products with industrial reality (e.g., moderated ramp-rate and minimum-duration requirements in reserves, clearer block structures and clearing schedules, and time-/location-conditioned capacity tariffs). The second cluster focuses on faster, clearer approvals via one-stop or parallel permitting, aligned timelines across authorities, and standardised data and documentation. As supporting enablers (not separate clusters), standardised telemetry/communication protocols and clear, user-friendly product summaries and forward guidance from TSOs/DSOs reduce informational and procedural complexity, especially for smaller actors.

Table 3-4: Overview of which specific solutions address the complex regulatory and market framework.

Complex regulatory and market framework	
Solution cluster	Specific solution
Market design	Clear product definitions
Market design	Product standardization and harmonization
Market design	Simplified and combined prequalification
Market design	Appropriate baseline methodologies
Market design	Clear settlement procedures
Regulatory and legal reform	Energy efficiency guidelines
Regulatory and legal reform	Improving permitting procedures
Regulatory and legal reform	Multiple BRPs at one EAN with submetering
Regulatory and legal reform	Forward guidance on energy policy
Market roles and responsibilities	Model agreements and standardised onboarding
Company-internal levers	Training & information sessions
Information and awareness	Enhancing market transparency and price visibility

Solutions targeting **increased operational expenditures** aim to reduce the direct and indirect costs of providing flexibility. Two levers dominate. First, enabling infrastructure (storage and process buffers, variable-speed drives, power-quality equipment, advanced metering and EMS) widens the safe operating window and mitigates cost exposure by shaving capacity peaks, shifting load away from high-tariff periods, improving dispatch accuracy, and reducing imbalance and non-delivery risks. Second, market design measures – such as longer lead times and adapted reserve product definitions – can reduce operational uncertainty and ease scheduling burdens. On the contractual side, pooling resources and aligning supply contracts with flexibility provision can enhance predictability, limit the impact on operations, and mitigate risks associated with non-availability. Grid tariff derogations and redesigned grid tariffs could directly alleviate the exposure to increased grid charges when providing flexibility.

Table 3-5: Overview of which specific solutions address increased operational expenditures

Increased operational expenditures	
Solution cluster	Specific solution
Infrastructure investment	Behind-the-meter investments
Market design	Product design adaptations
Market design	Appropriate baseline methodologies
Market roles and responsibilities	Pooling resources
Market roles and responsibilities	Operational guardrails
Market roles and responsibilities	Aligning supply contracts with flexibility participation

Regulatory and legal reform	Tariff derogation for flexible industries
Regulatory and legal reform	Grid tariff design
Public support mechanisms	Subsidised feasibility study
Company-internal levers	Mitigation strategies for flexibility cost risks

Solutions to **organisational misalignment** aim to realign internal structures and incentives and predominantly draw from company-internal levers. Aligning KPIs and employee bonuses, integrating flexibility into strategic plans, and creating structured feedback loops support a greater receptiveness to flexibility and its integration into core operations. Training and information sessions can build the necessary capacity across departments. Incremental investment approaches furthermore help to decrease the barrier to entry by reducing risk and allowing for gradual adaptation. Beyond these internal levers, pooling resources and standardised onboarding procedures address coordination challenges and could help companies that lack the internal resources.

Table 3-6: Overview of which specific solutions address the organisational misalignment

Organisational misalignment	
Solution cluster	Specific solution
Market design	Simplified and combined prequalification
Market design	Clear product definitions
Information and awareness	Showcasing
Information and awareness	Sector-specific awareness campaigns
Regulatory and legal reform	Forward guidance on energy policy
Market roles and responsibilities	Pooling resources
Market roles and responsibilities	Model agreements and standardised onboarding
Company-internal levers	Incremental investment approach
Company-internal levers	Adapted scheduling practices
Company-internal levers	Integrating flexibility in strategic plans
Company-internal levers	Aligning company KPIs
Company-internal levers	Training & information sessions
Company-internal levers	Aligning employee bonusses
Company-internal levers	Structured feedback loops

Solutions to **financing and investment constraints** aim to improve the bankability of flexibility projects by reducing risks and strengthening revenue expectations. A better integration of industrial flexibility in the Belgian CRM and risk-sharing arrangements between BRPs and flexibility providers contribute to this aim. Refined reserve product design and supply contract alignment strengthen revenue visibility. Public support mechanisms – including de-risking schemes, soft loans, tax incentives, and direct financial support – could help to reduce upfront capital requirements and improve access to finance. Complementary regulatory actions, such as the government providing forward guidance on energy policy or enhanced market transparency, foster investment confidence.

Table 3-7: Overview of which specific solutions address the financing and investment constraints

Financing and investment constraints	
Solution cluster	Specific solution
Market roles and responsibilities	Risk-sharing between BRPs and FSPs

Regulatory and legal reform	Forward guidance on energy policy
Public support mechanisms	Subsidised feasibility study
Public support mechanisms	De-risking mechanisms
Public support mechanisms	Soft-loans
Public support mechanisms	Tax credits
Public support mechanisms	Direct support
Company-internal levers	Internal shadow pricing model
Company-internal levers	Incremental investment approach
Information and awareness	Enhancing market transparency and price visibility

A range of measures could be leveraged to address **inadequate revenues from flexibility provision**, particularly market design adaptations and public support mechanisms. Adaptations to the design of ancillary service markets – such as introducing secondary capacity markets or revising penalty structures – can lead to more appropriate compensation and potentially unlock additional revenue. Public support mechanisms may, depending on their implementation, offer a direct approach to enhance revenues. Finally, at the company level, aligning energy procurement strategies with flexibility provision could significantly enhance the revenues derived from flexibility.

Table 3-8: Overview of which specific solutions address the inadequate revenues

Inadequate revenues	
Solution cluster	Specific solution
Market design	Product design adaptations
Market design	Enable value stacking
Market design	Product standardization and harmonization
Market design	Appropriate baseline methodologies
Market design	Clear settlement procedures
Market roles and responsibilities	Aligning supply contracts with flexibility participation
Regulatory and legal reform	Flexible connection agreements
Public support mechanisms	Soft-loans
Public support mechanisms	Tax credits
Public support mechanisms	Direct support
Public support mechanisms	Renewable energy pool
Company-internal levers	Energy procurement strategies

3.4 Qualitative assessment of flexibility solutions

This section qualitatively evaluates the solutions proposed to overcome key barriers to industrial flexibility. The evaluation is structured in three parts. Section 3.4.1 first introduces the KPIs that form the basis for the assessment. These indicators span multiple dimensions, including market efficiency, the grid operation, industrial competitiveness, effectiveness and scalability, proportionality, ease of implementation, and stakeholder acceptance. Together, these KPIs provide a framework for evaluating the merits and limitations of each solution.

Section 3.4.2 provides a synthesis of the proposed solutions. Each solution is evaluated across the seven key performance indicators, using a discrete scoring scale (low, medium, high) to reflect its expected desirability. In addition to this qualitative assessment, we assign a quantitative solution priority score to capture the practical relevance of each solution. Specifically, this metric links individual metrics to the most pressing barriers as identified by stakeholders. In Section 3.4.3, the analysis is further disaggregated through a sector-specific lens by computing the solution priority metric for each individual sector individually, i.e. only considering the most pressing barriers that that specific sector faces.

Note furthermore that the solution priority metric is based on input from industrial stakeholders, and, as such, reflects their perspective.

3.4.1 Key performance metrics

This section introduces seven KPIs to assess industrial flexibility solutions. They reflect the extent to which a solution helps reach a broader societal objective as well as the feasibility to implement the solution. The selected KPIs are as follows:

- **Electricity Market Efficiency** captures the extent to which a solution contributes to better market functioning. It covers wholesale electricity markets, ancillary services, imbalance settlement and the capacity remuneration mechanism. A solution scores high on this criterion if it improves price signals, reduces market distortions, and efficiently integrates flexible demand into market operations.
- **Grid Operation** evaluates how a solution supports the secure and efficient functioning of the electricity grid. This includes the ability to alleviate or cope with network congestion, to contribute to cost-effective grid planning and operation, and to be able to recover grid investment costs.
- **Industrial Competitiveness** reflects the economic implications of a solution for industrial actors. It considers whether a solution allows companies to manage energy costs, retain operational flexibility, and maintain or enhance competitiveness in the context of electrification and decarbonisation.
- **Effectiveness & Scalability** considers both the degree to which a solution addresses its targeted barriers and the extent to which it can be scaled across sectors. A solution with high scalability is more likely to generate systemic impact.
- **Proportionality** assesses whether the solutions are appropriate and necessary to mitigate one of the barriers, without being unduly burdensome or excessive in relation to the objective.
- **Ease of Implementation** assesses the practical complexity involved in putting a solution into practice. This includes technical readiness, legal and regulatory requirements, administrative burden, and the coordination effort required across actors.
- **Stakeholder Acceptance** captures the expected level of support or resistance from relevant stakeholders, including industrial firms, employees, regulators, service providers, and the general public. Solutions that align with stakeholder interests and are perceived as fair and beneficial are more likely to succeed.
- **Solution priority** captures the relative importance of the proposed solutions. We consider the stakeholders input on barrier priorities and the linkages between individual barriers and solutions to compute the following metric:

$$Solution\ priority_s = \sum_b BI_b \cdot L_{s,b}$$

  Where BI_b represents the barrier importance and $L_{s,b}$ is a binary parameter that equals one if solution s positively contributes to barrier b. Specifically, BI_b represents the average score (impact, urgency) based on the input that is consolidated in Figure 2-19. Alternatively, we could have presented the metric separately per dimension, i.e. one for impact and one for urgency, but this does not lead to additional insights. The metric is furthermore rescaled such that the maximum value equals 100. The interpretation is relatively straightforward: if a certain solution has twice the priority than another, it either contributes to (a) barrier(s) that are deemed twice as important, or it contributes to twice as many barriers of equal importance.

Taken together, these KPIs provide a framework for evaluating the merits and limitations of each solution. They help explore which measures are most efficient and effective, but also which are most promising from an implementation perspective. Note furthermore that these KPIs also represent various stakeholders. Electricity market efficiency primarily concerns system operators and electricity consumers. Grid operation is of particular relevance for system operators whereas industrial actors are most concerned with their competitiveness. Proportionality reflects a societal perspective and the remaining indicators – effectiveness & scalability, ease of implementation, and stakeholder acceptance – cut across multiple stakeholder groups.

3.4.2 General solution assessment

Figure 3-4 and Figure 3-5 summarize the outcome of the analysis and present an evaluation of the proposed solutions based on the seven qualitative KPIs as well as the quantitative priority metric. In what follows, we limit ourselves to general insights. Motivation for specific entries can be found in the Appendix of this deliverable.

Across all solution clusters, **market roles and responsibilities** is where industry most actively looks for actionable change. Within this cluster, two measures repeatedly surface with high priority from companies themselves: *joint operation and pooling of demand response* and *operational guardrails*. Together they are viewed by the companies as the solutions with a high urgency and impact, but they create non-trivial design and coordination challenges.

Joint operation and pooling can strongly enable participation by spreading operational responsibility, commercial exposure, and transaction costs, and by allowing shared or staged CAPEX. However, deeper industrial pooling has consequences for other stakeholders and is not just “standard aggregation.” Open issues include liability allocation, non-delivery risk split, data and privacy governance, baseline and metering granularity, and settlement flows. These are implementation issues that require explicit governance, standardised contracts, and interoperable data-exchange; they are feasible but far from trivial.

Operational guardrails (for example opt-out clauses, caps on activations, minimum notice) are requested by industry to protect process stability, delivery commitments, and OPEX exposure. Yet the same guardrails can diminish service effectiveness for other parties: looser limits cut availability, reduce dispatchability, and may degrade the technical suitability of the procured service for its purpose (for example frequency containment needs fast, firm response). The policy and product design task is to parameterise guardrails tightly enough to safeguard plants while preserving system value and market integrity.

Interestingly, firms rated *risk-sharing between BRP*, aggregator, and provider as less urgent, even though it scores very well across KPIs. Properly drafted risk-sharing contracts directly reduce downside risk for industrial sites, are proportionate because they can be tailored to participant size and technology, and are relatively easy to implement since they are primarily contractual. A caveat is stakeholder acceptance: BRPs may resist if the structure shifts imbalance or non-delivery exposure without commensurate control. The priority–KPI gap likely reflects time horizons: companies prioritise what unblocks them tomorrow (pooling, guardrails), whereas risk-sharing delivers large benefits but is perceived as “legal work” that can be done later. From a system perspective, however, getting risk-sharing templates in place early would accelerate take-up and lower the need for overly conservative guardrails.

Market design is the second solution cluster where firms most actively seek change. Three measures repeatedly receive high priority from companies: *product design adaptations, clear product definitions, and product standardisation and harmonisation*.

Product design adaptations are the top-ranked item within the market-design cluster from the companies’ perspective (i.e., on our urgency × impact priority metric). Their appeal is concrete: calibrated changes such as allowing 5–15 minute ramp windows in mFRR for electro-intensive processes, offering upward-only (or downward-only) products instead of mandatory symmetry, shortening minimum activation blocks (for example from 15 to 5 minutes), or using schedule-based baselines and clear settlement rules can bring currently excluded industrial assets into scope and raise effective participation. These adaptations are efficient only when tightly matched to a specific system use case: relaxed ramps and longer activation are appropriate for adequacy or congestion relief, while fast, firm response remains essential for frequency quality. Loosely targeted changes risk weakening product firmness, raising procurement costs, or degrading system performance. Most importantly, even though firms prioritise these adaptations, they are not an automatic “go-to” solution. They require formal regulatory changes and multi-stakeholder alignment, entail long lead times, and carry a real risk of product proliferation or diluted technical requirements if not piloted and specified carefully.

Clear product definitions also rank highly by companies and perform well across KPIs. By codifying who does what (e.g., BRP, BSP/aggregator, site operator), what must be measured and communicated (metering points, telemetry frequency and latency), how performance is calculated (baseline method, deadbands, pay-for-performance), and when penalties apply (tolerance bands, test regimes, non-delivery settlement and force-majeure rules), they remove ambiguity. Clear product definitions lower entry barriers, shorten onboarding, and are widely valued for the predictability they provide.

By contrast, *product standardisation and harmonisation*, though welcomed by the companies, score poorly on the KPI assessment in general. Implementation is demanding, since it requires alignment across TSOs/DSOs, regulators, platforms and vendors, plus concurrent updates to rulebooks and IT interfaces. The impact on unlocking additional flexibility is modest: uniform specifications tend to optimise for the “average” asset and response profile, which can under-reward or even exclude niche industrial capabilities such as long-duration discharge, asymmetric ramps, or site-specific telemetry constraints. Standardisation can improve liquidity and reduce transaction costs, but it does not necessarily expand technical potential and may narrow eligibility if common parameters are too tight.

Finally, *enabling value stacking* across services performs best in this cluster on effectiveness and efficiency: it allows assets to be used where they add the most system value, increases revenue potential, and strengthens investment incentives. Companies nevertheless rated it only medium in priority, likely because stacking introduces contractual and operational complexity (e.g. priority rules, business case assessment, and anti-double-counting) that many prefer to defer until templates and tooling mature.

Regulatory and legal reform emerges as a necessary but not urgent lever in the eyes of participating companies, in line with the observation in [146]. In the prioritisation, companies generally assign these measures lower immediacy and perceived impact. The KPI patterns point to trade-offs rather than a single silver bullet. Each solution performs well on some dimensions and less well on others: some score high on effectiveness (unlocking flexibility or competitiveness), others deliver strong grid-operation benefits yet add only modest new flexibility; still others improve market efficiency. What is uniform across this solution cluster is the low scoring on ease of implementation. Most solutions require formal rule changes, multi-party negotiations, and careful drafting of common frameworks, which makes delivery slow and resource intensive. Their effectiveness is nevertheless anticipated once enacted, but they rarely unlock flexibility on their own; they work best when paired with complementary actions in market design, contracting, and company-internal enablement.

Public support mechanisms feature prominently among the high-priority solutions from the company perspective. Direct support and tax credits are viewed as high-impact, near-term enablers because they cut revenue uncertainty, reduce risk exposure, and ease capital constraints. The KPI assessment, however, highlights material trade-offs. Proportionality is a recurring concern. Across this cluster, several instruments risk uneven support across companies, over-subsidisation, and perceptions of excessive intervention when targeting is weak. Designing fair allocation rules and eligibility criteria is administratively demanding and politically sensitive. Moreover, for direct support in particular, there is clear potential to distort price signals and reduce allocative efficiency.

One particularly noteworthy intervention is the *subsidised flexibility study*, which ranks moderate in solution priority and performs well across all KPIs. Beyond covering part of the early assessment costs, such studies raise internal awareness, support informed decision-making, and strengthen the credibility of project proposals. They also offer a low-risk, low-cost entry point for firms unfamiliar with industrial flexibility. However, compared with other public-support instruments, they are not very effective at directly resolving the key barriers identified by companies. Their primary value is as a first stepping stone: they help size the potential and de-risk the internal go/no-go, after which more substantive measures are needed to enable actual flexibility provision.

Overall, public-support instruments can be effective enablers of flexibility, but only if they are tightly targeted and include clear safeguards; without this discipline, the KPI-identified risks, including disproportionate support, fairness concerns and market distortions, may outweigh the benefits.

Company-internal levers sit mid-table in the priority rankings. Within this cluster, only the incremental investment approach is flagged by companies as a high-priority measure; the other levers are generally judged less urgent or less impactful than external reforms. This ordering reflects a pragmatic focus on changes that require coordination with markets and regulators first, with in-house adaptations viewed as follow-ons.

Effectiveness, however, tells a more nuanced story. Several internal measures are powerful at addressing core barriers when companies choose to deploy them: incremental investment approaches can lower organisational and financial thresholds to start, internal shadow-pricing models improve dispatch and project appraisal, energy-procurement strategies align contracting with flexibility value, and integrating flexibility into strategic plans and KPIs anchors the topic in governance and capital planning. Where implemented, these tools directly reduce evaluation uncertainty, make benefits visible in decision forums, and increase the likelihood that pilots scale.

The trade-off is implementation effort and acceptance. Many of the most effective internal levers require changes to routines and processes, advanced modelling capability or additional internal capacity, more complex contractual arrangements and market expertise, leadership buy-in, and in some cases culture change. Stakeholder acceptance can be mixed: revising company KPIs or linking bonuses to flexibility outcomes often meets resistance if perceived as unfair or misaligned with current roles. These frictions explain why companies rate many internal levers as less urgent even though they score well on several KPIs.

Within the cluster, two practical near-term options stand out. First, *mitigation strategies for flexibility cost risks* (for example, contractual protections, process buffers, conservative activation rules) receive moderate priority but score consistently well across KPIs because they reduce downside exposure without heavy system changes. Second, *training and information sessions* are simple yet effective: they build internal capability, counter scepticism, and are typically easy to roll out.

Overall, company-internal levers are not substitutes for market and regulatory enablers, but they are complementary accelerators; companies that adopt them early are better positioned to capture value once external conditions improve.

Infrastructure investments sit in the mid-to-lower tier of company priorities. Across this solution cluster, solutions struggle on ease of implementation and stakeholder acceptance because they are capital-intensive, require deep process integration, and often hinge on coordination with grid operators and vendors. In that sense they mirror company-internal levers: effective when in place, but hard to push through. On the upside, they score well on effectiveness and proportionality, when deployed, behind-the-meter assets, buffer capacity, and grid reinforcements directly expand the technical envelope for flexibility in a way that is targeted to site needs.

Within this cluster of solutions, *plug-and-play IT modules* perform best overall: they lower integration frictions, improve interoperability, and can be rolled out incrementally, which increases acceptance relative to heavy CAPEX options.

Information & awareness. This cluster sits in the lower segment of company-derived priorities: companies do not consider these measures critical for unlocking flexibility in the short term. Nevertheless, sector-specific awareness campaigns and showcasing of real industrial cases perform strongly across KPIs, particularly on effectiveness, scalability, and proportionality, without generating heavy implementation burdens or requiring extensive stakeholder involvement. These instruments are easy to roll out and can shift internal perceptions, especially in companies with limited knowledge on flexibility or energy market functioning in general. However, their effectiveness depends on integration: they work best when paired with more operational tools such as onboarding templates or feasibility studies. As such, companies see information measures less as direct enablers and more as soft accelerators that de-risk early steps and improve decision quality.

Taken together, this reinforces that there is no single silver bullet. High-impact flexibility requires coordinated progress: targeted infrastructure where it truly unlocks capacity, paired with market-design adaptations, selective regulatory adjustments, and firm-level engagement. Physical investments remain foundational, but their feasibility and attractiveness improve markedly when bundled with enabling rules and, where warranted, well-targeted public support.

Category	Solution	Market Efficiency	Grid Operation	Industrial Competitiveness	Effectiveness & scalability	Proportionality	Ease of Implementation	Stakeholder Acceptance	Priority
Market roles and responsibilities	Pooling resources	1	0	0	1	1	-1	1	100
	Operational guardrails	-1	1	0	-1	1	1	1	87
	Model agreements and standarised onboarding	0	0	0	1	1	0	0	42
	Alligning supply contracts with flexibility participation	1	0	1	1	1	0	0	22
	Risk-sharing between BRP aggregator and flexibility provider	0	0	1	1	1	1	0	9
Public support mechanisms	Direct support	-1	0	1	1	-1	0	0	76
	Tax credits	0	0	1	1	-1	1	0	76
	Subsidised feasibility study	0	0	0	0	0	1	1	57
	Soft-loans	0	0	1	1	-1	1	0	44
	De-risking mechanisms	-1	0	1	1	-1	-1	0	40
	Renewable energy pool	1	0	0	1	0	-1	0	11
Information & awareness	Showcasing	0	0	0	1	1	0	1	57
	Sector-specific awareness campaigns	0	0	0	1	1	1	1	51
	Enhancing market transparancy and price visibility	1	0	0	1	1	-1	1	34
Regulatory and legal reform	Improve permitting procedures	0	1	1	1	-1	-1	-1	40
	Flexible connection agreements	-1	1	0	0	0	0	0	33
	Forward guidance on energy policy	0	0	0	1	1	-1	1	22
	Reduction of tariffs for flexible industries	1	-1	1	1	-1	0	-1	18
	Grid tariff design	1	0	0	1	0	-1	-1	18
	Allow for multiple BRPs at one EAN with submetering	1	0	1	1	1	-1	0	13
	Energy efficiency guidelines	0	0	0	0	1	1	0	8

Figure 3-4: Overall solution evaluation, part 1 out of 2.

	Solution	Market Efficiency	Grid Operation	Industrial Competitiveness	Effectiveness & scalability	Proportionality	Ease of Implementation	Stakeholder Acceptance	Priority
Market design	Product design adaptations	1	0	1	1	0	-1	0	95
	Clear product definitions	1	1	0	1	1	1	1	69
	Product standardization and harmonization	1	0	0	-1	1	-1	0	66
	Enable value stacking	1	1	1	1	0	1	1	37
	Appropriate baseline methodologies	0	0	0	0	0	0	-1	25
	Simplified and combined prequalification	0	0	0	1	-1	0	0	14
	Clear settlement procedures	0	0	0	0	1	1	1	6
Infrastructure investment	Production or buffer capacity	0	0	0	1	1	-1	-1	63
	Behind-the-meter investments	0	1	0	1	1	-1	0	56
	Grid reinforcements	1	1	1	1	1	-1	-1	37
	Plug-and-play IT modules	0	0	0	1	1	0	1	21
	Standarized communication protocols	0	0	0	1	1	-1	-1	21
Company-internal levers	Incremental investment approach	0	0	0	1	1	1	1	75
	Mitigation strategies for flexibility cost risks	0	0	0	0	1	1	1	48
	Training & information sessions	0	0	0	0	1	1	0	47
	Structured feedback loops	0	0	0	0	0	0	0	41
	Adapted scheduling practices	0	0	1	0	1	-1	-1	37
	Internal shadow pricing model	0	0	0	1	1	-1	1	31
	Energy procurement strategies	1	0	1	1	1	-1	0	25
	Aligning company KPIs	0	0	0	1	1	0	-1	19
	Aligninining employee bonusses	0	0	0	0	1	1	-1	15
	Integrating flexibility in strategic plans	0	0	1	1	1	-1	0	11

Figure 3-5: Overall solution evaluation, part 2 out of 2.

3.4.3 Sector-specific solution assessment

While the previous analysis presented a general overview of solution priorities across the industrial landscape, flexibility barriers, and hence effective solutions, can vary significantly between sectors. This section explores sector-specific priorities by assigning a solution priority metric per sector. This allows us to assess whether certain solutions are more or less relevant depending on the specific industrial context and to what extent tailoring of flexibility policies may be warranted. In order to provide sectoral insights, for each solution a priority score is calculated (using the same methodology as elaborated in Section 3.4.1), using only the specific feedback on the barriers and solutions provided by the stakeholders within each sector.

The sector-specific priorities are presented Figure 3-6. Note that the 'All' column reflects the general solution-priorities and comprises the same entries as Figure 3-4 and Figure 3-5. Note furthermore that the values have been normalised per sector. As such, entries are directly comparable column-wise, but not row-wise.

For ***datacentres***, the highest-priority solutions reflect the sector's need to guarantee uninterrupted service provision throughout time. Depending on the specific circumstances, they may need to invest in additional behind-the-meter equipment to be able to offer flexibility to the electricity system. They furthermore struggle to obtain grid connection capacity and could benefit from grid reinforcements or a better (re)allocation of flexible connection agreements. In contrast, behavioural or incentive-based measures play a lesser role in this context.

The ***chemical sector*** shows a preference for a diverse portfolio of solutions, with relatively high scores spread across infrastructure investments, market design, regulatory improvements, and company-internal levers. Notably, incremental investment strategies are ranked extremely high. This results from the sector's long project cycles and capital-intensive assets as well as the public opposition faced by flexibility initiatives. Public support mechanisms are also highly prioritised, indicating the importance of de-risking for unlocking investment. In contrast to datacentres, the sector sees strong value in training and internal capacity-building, possibly due to the complexity of processes and the importance of integrated planning.

The ***food sector*** assigns particular importance to market design interventions, notably product design adaptations and clear product definitions. This reflects a key concern in the sector: inadequate and uncertain revenues from flexibility provision. These market-related aspects are seen as fundamental barriers, and improving product design is considered essential to unlock meaningful participation. In line with this revenue focus, the food sector also attributed relatively high value to direct public support and tax credits, as these can complement market income and improve the business case for investment. Beyond these priority measures, the sector displays a broad distribution of moderately relevant barriers, with no single dominant concern. As a result, a number of additional solutions, such as feasibility studies, showcasing, and training sessions, score reasonably well.

Flexibility solutions for the ***iron and steel sector*** show a more targeted pattern, dominated by high scores for pooling of flexibility resources, operational guardrails, and incremental investment approaches. The sector prefers low-disruption strategies that help manage flexibility without overhauling core processes. Importantly, these measures also help the sector cope with a lack of in-house capabilities (both technical and organisational) to manage flexibility autonomously. The interest in guardrails and aggregator partnerships highlights the sector's reliance on external coordination. Similarly, incremental investments offer a way to test and gradually build internal expertise without committing to large-scale, long-term changes.

The ***non-ferrous metals sector*** exhibits a distinct profile, reflecting the fact that this industry is already relatively advanced in their flexibility provision. As a result, many internal barriers (e.g. lack of awareness, organisational resistance, etc.) are perceived as less pressing or have already been addressed. Instead, the focus is on how to optimally valorise existing flexibility potential, and how to expand it. In particular, the sector prioritises measures that improve market access and revenue predictability, without leading to increased operational expenses such as wear and tear. This explains the moderate but consistent interest in operational guardrails and mitigation of flexibility-related cost risks. These measures are valued not as enablers of initial participation, but rather as tools to safeguard and refine ongoing flexibility provision.

This sectoral breakdown shows that flexibility solutions are not equally relevant across industrial sectors, and that policy design could account for these differences. While some solutions, such as pooling of resources, clear product definitions, and training and information sessions, are valued broadly, many others reveal a sharp variation depending on sector-specific contexts and the maturity of internal flexibility process.

Indeed, the non-ferrous metals sector, which already possesses relatively advanced internal flexibility capabilities, places less emphasis on awareness-building or organisational change as they may already have passed that stage. Instead, it desires fine-tuning the value of existing flexibility through improved market design, cost mitigation, and targeted support to avoid negative operational impacts. In contrast, sectors such as iron and steel continue to face significant internal organisational capacity constraints. These companies seek solutions that reduce internal effort and risk, such as collective arrangement, and pathways to gradually build up internal capabilities through external partnerships or incremental approaches. Beyond these sector-specific preferences, the analysis hence highlights that solutions must be tailored to the stage of flexibility adoptions, as sectors with more experience face difference challenges than those just beginning the transition.

Category	Measure	Datacenters	Chemicals	Food	Iron & steel	Non-ferreous	All
Market roles and responsibilities	Pooling resources	69	27	42	100	52	100
	Operational guardrails	75	27	31	45	100	87
	Model agreements	0	54	10	56	13	42
	Alligning supply contracts	0	0	32	16	14	22
	Risk-sharing between BRPs and FSPs	0	51	10	0	19	9
Public support mechanisms	Direct support	28	85	57	60	19	76
	Tax credits	28	85	57	60	19	76
	Subsidised feasibility study	0	100	24	24	69	57
	Soft-loans	0	58	26	44	19	44
	De-risking mechanisms	0	58	39	24	19	40
	Renewable energy pool	0	27	19	0	0	11
Information & awareness	Showcasing	25	73	41	34	26	57
	Sector-specific awareness campaigns	0	48	53	34	33	51
	Market transparency and price visibility	25	51	34	0	19	34
Regulatory and legal reform	Improve permitting procedures	56	52	0	15	21	40
	Flexible connection agreements	72	20	8	0	15	33
	Forward guidance on energy policy	0	23	23	17	9	22
	Tariff derogation for flexible industries	0	25	21	0	24	18
	Grid tariff granularity	0	25	21	0	24	18
	Multiple BRPs at one EAN	19	2	0	15	0	13
	Energy efficiency guidelines	0	0	11	0	15	8

Category	Measure	Datacenters	Chemicals	Food	Iron & steel	Non-ferreous	All
Market design	Product design adaptations	63	54	100	33	62	95
	Clear product definitions	81	81	26	32	21	69
	Product standardization and harmonization	100	72	8	15	45	66
	Enable value stacking	28	27	41	16	9	37
	Appropriate baseline methodologies	0	0	30	17	26	25
	Simplified and combined prequalification	0	27	15	0	14	14
	Clear settlement procedures	0	0	8	0	9	6
Infrastructure investment	Production or buffer capacity	97	83	22	1	36	63
	Behind-the-meter investments	81	0	29	20	46	56
	Grid reinforcements	81	20	0	0	29	37
	Plug-and-play IT modules	0	54	11	0	27	21
	Standarized communication protocols	0	54	11	0	27	21
Company-internal levers	Incremental investment approach	25	100	43	54	37	75
	Flexibility risk mitigation strategies	0	25	32	40	52	48
	Training & information sessions	25	54	22	34	25	47
	Structured feedback loops	59	49	17	0	28	41
	Adapted scheduling practices	34	0	17	22	36	37
	Internal shadow pricing model	0	80	11	17	19	31
	Energy procurement strategies	0	0	27	36	0	25
	Aligning company KPIs	0	27	23	0	23	19
	Aligninig employee bonusses	25	25	0	0	8	15
	Integrating flexibility in strategic plans	0	0	17	0	17	11

Figure 3-6: Sector specific priorities.

3.5 Conclusions on solutions to industrial flexibility

This Chapter has compiled and evaluated a set of 43 practical solutions to overcome critical barriers to industrial flexibility. The selection is based on both desk research and direct input from industrial stakeholders, ensuring that the measures address practical obstacles. Each solution was linked to critical barriers retained form Chapter 2 and assessed across multiple performance criteria, including electricity market efficiency, grid operation, industrial competitiveness, ease of implementation, and stakeholder acceptance. In addition, we assigned a quantitative importance measure to each solution, both in general (Section 3.4.2) and for specific sectors (Section 3.4.3), based on (i) how solutions contribute to individual barriers and (ii) how important the barriers are to the industrial partners.

After comprehensively discussing the individual solutions, we clustered the barriers and associated solutions based on their interlinkages. Solutions were clustered according to which barriers they can jointly address, allowing for a more high-level overview that allows to identify which solutions are most relevant for specific challenges that a company is facing. For example, technological and operational limitations can typically be addressed through a mix of infrastructure upgrades (e.g. batteries, buffer capacity), market reforms (e.g. more adaptable reserve products), and internal risk mitigation measures (e.g. operational guardrails). This mapping of solution and barrier clusters furthermore highlights where solutions can provide simultaneous impact on multiple barrier types.

The solution assessment reveals that no single type of intervention is likely to be sufficient to unlock industrial flexibility on its own. Some of the highest-ranked solutions (e.g. joint pooling, incremental investment strategies, and product definition adaptations) combine practical feasibility with high impact. On the other hand, capital-intensive infrastructure upgrades such as batteries and process adaptations, while critical in some cases, often require complementary actions (e.g. de-risking instruments, streamlined permitting, regulatory clarity).

Finally, the sector-specific analysis highlights the importance of tailoring strategies to sectoral realities and maturity levels. Sectors that are already advanced in flexibility providing benefit more from fine-tuning value capture and risk mitigation. In contrast, sectors not yet familiar with flexibility provision benefit more from foundational enablers that lower internal barriers or improve revenue certainty. Again, flexibility cannot be unlocked by individual measures but require coordinated action adapted to the specific needs of each industrial sector.

4. Conclusions

This study maps the barriers to industrial flexibility in Belgium. We combine a structured literature review with interviews and workshops with Belgian companies. We build a common taxonomy across seven categories and link practical experiences from the sector one to one to that set. In particular, we run deep dives in chemicals, commercial data centres, food, iron and steel, and non-ferrous metals. Companies prioritise the sector barriers by impact and urgency. Following on, we assess 43 practical solutions using a set of KPIs and an industry-derived priority metric. We group the measures into seven solution clusters and map each to the barriers they address. The result is a ranked view of blockers and a compact menu of solutions per sector and for cross-sector use.

The barrier analysis points to a clear centre of gravity. Economic and technological constraints dominate in the literature and in company interactions, which confirms their central place in any Belgian strategy for demand-side participation. When urgency and relevance, according to the companies, are read together, three near-term blockers stand out across all sectors; i) grid capacity and connection certainty determine whether assets can participate and when they can do so, ii) quality risk in production limits the feasible operating window for modulation and defines how much flexibility is acceptable without jeopardising output or specifications, and iii) revenue uncertainty weakens business cases through variable activation volumes, exposure to baseline and settlement rules, and interactions with supply contracts that shape net value. These priorities recur in the sector snapshots and frame where near-term action is most likely to pay off.

Sector context sharpens this picture. For the chemical sector, most barriers are of a technological nature. Chemicals run continuous, heat-integrated trains with strict product specifications, where short-notice ramps can shorten catalyst life, upset selectivity and conversions, and trigger off-spec and flaring. Commercial data centres carry firm IT load and often face saturated urban grids, which shifts attention to limited flexibility potential and the predictability of grid access. Food processing is shaped by quality and safety requirements and often sees economic and organisational constraints in front of technical headroom, which tilts decisions toward efficiency gains unless flexibility can be operationalised without quality risk. Iron and steel operate sequence-dependent routes where breaking campaigns raises cost and work-in-process and compresses the room for short-notice response. Non-ferrous production faces informational and organisational gaps alongside process constraints and tight grid access. Investment typically proceeds only once product eligibility, prequalification requirements and access conditions are clearly defined. These sector observations confirm that one size is inefficient and that the expression of barriers is process- and site-specific.

The prioritisation step connects company views to the taxonomy. Companies ranked sector-specific barriers by impact and urgency, and those barriers were then mapped back to the general set. The outcome shows both convergence and dispersion. Some general barriers appear across multiple sectors with similar priority, which indicates universal challenges (i.e. grid capacity and connection certainty, quality risk in production, and revenue uncertainty). Others change rank across sectors, which points to different operational realities and to the need for tailored responses.

We organise the measures into seven families that cover the identified solution framework: market roles and responsibilities, market design, regulatory and legal, public support, infrastructure, company-internal levers, and information and awareness. Together they cover a full spectrum. At one end sit low-lift steps inside the company and straight information tools that a company can deploy quickly. At the other end sit structural changes to products, rules and access that require coordination, formal decisions and time. Each measure is linked to the barriers it addresses and is assessed on seven KPIs alongside the priority signal from companies.

The solution assessment does not recommend a single instrument. Rather, it condenses into three cross-cutting lessons about what reduces friction, what makes projects bankable, and what accelerates early steps. They translate the barrier picture into a practical agenda that can be sequenced and adapted to sector context.

The first lesson is that clarity reduces friction at entry. Companies are more likely to engage when participation is straightforward, predictable, and manageable. Clear product definitions remove ambiguity on roles, data requirements, performance metrics, and settlement rules. Practical onboarding templates and streamlined prequalification help internal decision-making and lower the activation threshold. Solutions like pooling and operational guardrails further support entry by sharing risk, cost, and responsibility. However, they require coordinated governance, standardised contracts, and interoperable data flows. When these conditions are met, even less mature companies can access flexibility markets with confidence and stability.

The second lesson is that bankability depends on fit-for-purpose product design, credible risk sharing, and early-stage de-risking. A viable business case is shaped not just by revenue potential, but by how risk is allocated and how well market products align with operational realities. Targeted product adaptations, such as shorter activation times, asymmetric bids, or relaxed ramping, can unlock participation if they are calibrated to specific system needs. Risk-sharing contracts between BRPs, aggregators, and providers are critical to protect industrial actors from imbalance and delivery exposure, particularly for newcomers. Public support instruments, including feasibility study subsidies and tax credits, help de-risk early steps, especially in capital-intensive sectors. These measures enhance financial viability and reduce the need for overly conservative participation rules.

The third lesson is that flexibility adoption is path-dependent: timing, maturity, and internal readiness matter. Flexibility solutions must be matched to the specific stage of organisational and sectoral development. Early-stage sectors, like food or iron and steel, benefit most from foundational enablers: clear guidance, templates, external coordination, and gradual investment strategies. More advanced sectors, such as non-ferrous metals, seek to optimise participation through value refinement, risk cost mitigation, and stable revenue models. This implies a need for tailored implementation. Policy design should avoid one-size-fits-all approaches and instead support differentiated trajectories that reflect internal capabilities, external constraints, and the learning curve companies are navigating.

Finally, structural enablers require coordination, not just incentives. Unlocking flexibility at scale goes beyond individual business cases. Many of the most impactful levers, such as pooling arrangements, operational guardrails, product standardisation, or IT interoperability, depend on multi-actor alignment. BRPs, DSOs, TSOs, regulators and aggregators must coordinate to ensure that enabling conditions are in place. Even technically feasible solutions struggle to scale when governance is unclear or interfaces are misaligned. Flexible participation thrives in systems where roles are well defined, data flows are standardised, and contractual templates align incentives across stakeholders.

Implementation should follow a sequenced path that reflects sector realities. No single lever unlocks flexibility on its own. Progress is cumulative and depends on coordinated movement across solution families. Early steps should focus on clarity at the point of entry through product definitions, practical onboarding and defined roles and responsibilities. In parallel, prepare complementary measures that firms can adopt as external enablers mature. Targeted product adaptations and fair risk allocation improve bankability and allow more processes to find a viable product fit. Information measures and modular IT support capability building and shorten the path to first participation. Infrastructure investment and deeper process adaptations come later for most firms, once the business case and operational conditions are proven.

In the implementation of the solutions, policy makers should prioritise predictability, proportionality, and sequencing. System operators and platforms should focus on transparency, validation, and interoperability. Companies should prepare internally through capacity building and process alignment. Aggregators and BRPs should co-develop actionable templates for pooling, risk-sharing, and operational boundaries. Taken together, these insights underline that unlocking industrial flexibility is not a single action but a coordinated journey.

Scope and limitations should be acknowledged. The analysis combines literature and company input, yet it does not claim to cover every process variant or every site condition in Belgium. KPI assessments are qualitative by design. They are intended to support comparison and prioritisation rather than to deliver a single numerical answer. The mapping between sector-specific and general barriers improves comparability, yet it does not erase the need for site-level diagnosis before investment. The solution set is practical and diverse, but the conclusions do not argue for uniform roll-out. They point to combinations that are likely to work and to an order that reduces risk while raising take-up.

What readers should take away is straightforward. Industrial flexibility is constrained by real process limits and by economic exposure. Three blockers recur across sectors and should anchor near-term action. Clarity at entry reduces friction. Targeted product design and credible allocation of risk improve bankability. Information measures and modular IT accelerate early steps but do not substitute for structural enablers. Sector context and maturity shape what works and when it works. The study provides a common taxonomy, a cross-sector mapping and an evaluation frame that support joint planning by industry, market actors and public authorities.

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6. Appendix

6.1 Detailed overview of sector-specific barriers according to their priority level

Table 6-1: Overview of sector-specific barriers according to their priority level

High Priority	Medium priority	Low priority
Ch1	Co4	Ch4
Ch2	Co6	Ch8
Ch3	Fo3	Ch9
Ch5	Fo4	Ch10
Ch6	Fo5	Ch12
Ch7	Fo6	Ch13
Ch11	Fo8	Ch18
Ch14	Fo10	Co2
Ch15	Fo16	Co5
Ch16	Fo17	Co10
Ch17	Fo18	Fo2
Ch19	Fo19	Fo21
Ch20	Fo22	Fo27
Co1	Fo24	Nf6
Co3	Fo28	Nf12
Co7	Fo29	Nf15
Co8	Fo30	Nf16
Co9	Fo31	Nf17
Fo1	Fo32	Nf18
Fo7	Fo33	Ir2
Fo9	Fo34	Ir6
Fo11	Fo36	Ir10
Fo12	Fo37	Ir12
Fo13	Fo40	
Fo14	Fo42	
Fo15	Nf4	
Fo20	Nf14	
Fo23	Ir1	
Fo25	Ir3	

Fo26	Ir9	
Fo35		
Fo38		
Fo39		
Fo41		
Nf1		
Nf2		
Nf3		
Nf5		
Nf7		
Nf8		
Nf9		
Nf10		
Nf11		
Nf13		
Ir4		
Ir5		
Ir7		
Ir8		
Ir11		
Ir13		

6.2 Motivation for KPI evaluation of solutions

Table 6-2: Motivation for qualitative solution evaluation.

Market roles and responsibilities	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Pooling resources: joint operation and management of DR	High: Aggregation enables participation of small assets, improving market liquidity.	Neutral: Neutral effect unless pooling includes coordinated grid interaction.	Neutral: Cost savings likely, but extent depends on contractual agreements and actual activations.	High: Key enabler for participation by companies that are smaller or do not host the internal capabilities.	High: Allows scalable, modular participation.	Low: Requires governance, IT infrastructure and contractual agreements; not trivial.	High: Generally supported due to collective benefits, reduced employee workload and possibilities to mitigate process risks.
Operational guardrails	Low: Can restrict participation and the efficient allocation of resources if overly restrictive.	High: Limits peaks and ramping events so protects system reliability.	Neutral: Adds constraints that could mitigate flexibility provision, impact depends on severity of these limitations	Low: Inherently limits flexibility provision.	High: Guardrails can be scaled to technological risks, preserving proportionality.	High: Typically straightforward to codify and apply.	High: Generally welcomed by process operators.
Model agreements and standardised onboarding	Neutral: May streamline participation but has little direct effect on price formation or efficiency.	Low: No direct impact on grid operations.	Low: Administrative ease may lower entry costs but does not significantly affect competitiveness.	High: Reduces participation barriers, thereby helping to unlock flexibility.	High: Provides uniform processes adaptable to varying scales.	Neutral: Standardisation takes time and coordination across actors.	Neutral: May face inertia but generally non-controversial.
Risk-sharing between BRPs and FSPs	Neutral: Indirect effect via smoother participation, but does not fundamentally change market outcomes.	Neutral: No direct impact on grid operations.	High: Directly reduces downside risks for industrial participants.	High: Encourages participation by lowering perceived risks.	High: Can be tailored to size and nature of participants.	High: Internal contractual solution; relatively simple once agreements are established.	Neutral: Generally favourable for industrial parties, but may not be welcomed by BRPs.
Aligning supply contracts with flexibility participation	High: Ensures that contractual arrangements reflect market prices and that industrial companies have incentives to act upon market signals.	Neutral: Limited direct impact on grid operations.	High: Tailored contracts can reduce costs and/or create new revenue streams.	High: Directly supports flexibility by providing clear incentives.	High: Adjustments are contract-based and on a case-by-case basis.	Neutral: Requires bilateral negotiation, which can be time-consuming.	Neutral: Positive for industrial parties whereas the counterparties may be neutral.

Public support mechanisms	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Direct support	Low: Significant potential to distort price signals and reduce allocative efficiency.	Neutral: No direct impact on grid operations.	High: Provides direct economic benefit.	High: Strong incentive for considering and implementing flexibility options.	Low: broad grants risk over-subs. and windfall gains, often paying for infra-marginal projects rather than the specific flexibility gap.	Neutral: Requires administratively determined rules, but not overly complex.	Neutral: Positive for industries, may face scepticism due to fairness or distribution concerns.
Tax credits	Neutral: Can be designed to not interfere with market efficiency.	Neutral: No direct impact on grid operations.	High: Reduces tax burden, enhancing industrial competitiveness.	High: Provides incentives that support flexible investments.	Low: benefits scale with taxable profit and CAPEX, favouring larger, profitable firms and capex-heavy options rather than need or system value.	High: Implementable via existing fiscal structures.	Neutral: May be viewed neutrally due to indirect nature, although distributional concerns remain.
Subsidised feasibility study	Neutral: No market impact, purely informational.	Neutral: No direct impact on grid operations.	Neutral: Potential indirect effect, but not a significant one.	Neutral: Incentive for considering flexibility options and support informed-decision making, but no guarantees on implementation.	Neutral: Generally neutral, depends on targeting.	High: Low-cost, administratively simple.	High: Widely accepted as low-risk support.
Soft-loans	Neutral: Maintains market price signals without distortion.	Neutral: No direct impact on grid operations.	High: Enhances competitiveness via cheaper access to capital.	High: Encourages flexible investments through better financing conditions.	Low: Difficult to target, may offer too much support relative to actual risk.	High: Relatively simple to design.	Neutral: Typically lower direct support than alternative measures, fewer distributional concerns.
De-risking mechanisms	Low: High potential to distort price signals by shielding market participants.	Neutral: No direct impact on grid operations.	High: Improves competitiveness by lowering perceived risk and enables access to capital.	High: Unlocks flexibility by improving investment certainty.	Low: May be seen as excessive intervention with limited targeting.	Low: Extremely complex to design.	Neutral: May raise concerns about moral hazard or uneven benefit.
Renewable energy pool	High: Enhancing market efficiency by exposing demand to market signals.	Neutral: No direct impact on grid operations.	Neutral: No direct impact on cost competitiveness.	Neutral: Encourages participations by better price-exposure.	Neutral: Considered proportionate as it shares costs/benefits.	High: Complex to design, set up, and manage.	Neutral: generally neutral, depends on increase in complexity.

Information and awareness	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Showcasing	Neutral: No direct effect on prices or market efficiency.	Neutral: No direct impact on grid operations.	Neutral: No immediate effect.	High: Demonstrates value of flexibility, encouraging replication.	High: Proportionate as it uses real examples without direct subsidies.	Neutral: Requires coordination but no complex implementation.	High: Generally well accepted, concrete and relatable examples, and limited expenditures.
Sector-specific awareness campaigns	Neutral: No direct effect on prices or market efficiency.	Neutral: No direct impact on grid operations.	Neutral: No immediate effect.	High: Tailored campaigns can target sector-specific concerns.	High: Low-cost and targeted, making them highly proportionate.	High: Easy to deploy using existing communication channels.	High: Generally well accepted due to clarity and limited expenditures.
Enhancing market transparency and price visibility	High: Increases market transparency and aligns longer-term investment decisions.	Neutral: No direct impact on grid operations.	Neutral: Indirect effect, but rather small.	High: Transparency can trigger flexible responses to price signals.	High: Strong justification with limited public expense.	Low: Requires structural changes and accurate long-term forecasts.	High: Widely supported for promoting understanding.
Regulatory and legal reform							
Improve permitting procedures	Neutral: Allows to more quickly integrate flexible resources, but indirect effect.	High: Supports grid operation by expediting project timelines.	High: Enhances competitiveness through faster project rollouts.	High: Clear positive effect as it accelerates project deployment.	Low: May impose additional burdens, difficult to justify from solely a flexible perspective.	Low: Very complex due to required regulatory changes.	Low: Positive for industries, but likely poorly received by many other stakeholders.
Flexible connection agreements	Low: No guarantee that capacity gets allocated to most valuable consumers.	High: Facilitates grid operation through interruptible agreements.	Neutral: indirect effect. Positive for flexible processes but significantly hinders inflexible ones.	Neutral: Provides incentives to limitedly respond, only when required.	Neutral: Fairly proportional, balanced benefits and costs, at least on the short-term.	Neutral: Tricky to design but implementation is limited complex once framework is determined.	Neutral: Acceptance depends on implementation details and varies by company characteristics.
Forward guidance on energy policy	Neutral: Very indirect effect as it may allow to integrate efficient resources long-term.	Neutral: No direct effect on grid operation.	Neutral: Indirect effect as it may support long-term investments.	High: Removes policy uncertainty and helps trigger investments.	High: Provides clarity without strong interventions.	Low: Difficult to agree upon common framework.	High: Policy transparency is accepted by most.

Regulatory and legal reform	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Reduction of tariffs for flexible industries	High: Directly incentivises flexible operation in electricity markets.	Low: Likely causes excessive peaks and cost-recovery concerns.	High: Lower operational expenditures supports competitiveness.	High: Highly effective in optimising flexibility.	Low: risks over-compensation and can undermine cost-reflective signals; hard to target proportionately even with eligibility criteria	Neutral: Limited complexity to implement once tariff discussions are negotiated	Low: Grid costs fall upon other parties, distributional concerns arise.
Grid tariff design	High: Enhances efficiency by enabling more flexible operation in markets.	Neutral: Can be positive or negative depending on the design	Neutral: Can be positive or negative, depending on adjustment.	High: Unlocks flexibility by optimising demand response.	Neutral: Fairly proportional if rational grid usage is considered	Low: Difficult to implement, subject to minimal lead-times.	Low: Significant distributional effects are bound to arise.
Multiple BRPs at one EAN with sub-metering	High: increases efficiency by unlocking more market participants.	Neutral: No direct impact on grid operations.	High: Allows better energy management, but only for a select few.	High: Allows to include more resources, but total potential is limited.	High: Rather targeted and addresses a current regulatory imperfection.	Low: Requires updating the regulatory framework and settlement	Neutral: Depends on impact on affected stakeholders.
Energy efficiency guidelines	High: No direct effect on market efficiency.	Neutral: No direct impact on grid operations.	Neutral: Indirect effect.	Neutral: Positive for industries where providing flexibility compromises efficiency.	High: Proportional, no industry-wide impact expected.	Neutral: New methodology required, main burden is consultation and drafting, not legislation.	Neutral: Generally accepted across stakeholders.
Market design							
Clear product definitions	High: Reduces complexity and enhances market liquidity.	High: Including congestion products may enhance grid operations.	Neutral: No direct impact.	High: Clear lower participation barriers for participants.	High: Transparent rules apply equally to all participants.	High: Definitions can be readily developed.	High: Most stakeholders value clarity and predictability in market rules.
Product standardization and harmonization	High: Standardized products reduce transaction complexity.	Neutral: No direct impact on grid operations.	Neutral: No direct effect.	Low: Standardization may oversimplify, excluding niche flexibilities.	High: uniform, transparent product specs across actors/regions apply equally and reduce arbitrary disparities	Low: Requires alignment across multiple jurisdictions and across multiple actors.	Neutral: Divided, some will benefit, others lose existing opportunities.

Market design	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Product design adaptations	High: Tailored products better match system needs and improve economic signals.	Neutral: No direct effect.	High: Market design could better award industrial flexibility.	High: Opens the market to otherwise excluded assets.	Neutral: Depends on the specific design.	Low: Requires regulatory change and stakeholder negotiation.	Neutral: Mixed, some will benefit and others will not.
Simplified and combined prequalification	Neutral: Limited unless entry leads to more active participants.	Neutral: No direct effect.	Neutral: Very indirect effect, but particularly relevant for smaller players.	High: Eases entry for untapped assets.	Low: Risk that simplicity favours certain asset types.	Neutral: Procedural change is feasible but requires alignment.	Neutral: Generally neutral, though incumbent actors may be cautious.
Enable value stacking	High: Enables optimal use of flexibility across services.	High: Improves system operation by leveraging flexibility.	High: Increases revenue potential and the return for flexibility investments.	High: Offers strong incentive to participate.	Neutral: Generally neutral, but needs rules to avoid overcompensation or exclusivity.	High: Can build on existing platforms and mechanisms.	High: Broad support, particularly from aggregators and industry.
Appropriate baseline methodologies	Neutral: Impact depends on design quality.	Neutral: No direct link.	Neutral: Not a strong link.	Neutral: Fair compensation is essential, but does not directly incentivize flexibility.	Neutral: Strongly depends on the design.	Neutral: Technically feasible, but deciding upon a baseline is sensitive.	Low: Generally controversial due to lack in accuracy, depends on design.
Clear settlement procedures	Neutral: Does not directly improve efficiency.	Neutral: No direct link.	Neutral: Not a strong link.	Neutral: Could help but does not provide a direct incentive.	High: Clear rules reduce risk of bias or arbitrary treatment.	High: Procedure-focuses changes, deemed feasible.	High: Welcomed for increasing transparency and predictability.

Infrastructure investment	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Production or buffer capacity	Neutral: Does not directly improve market efficiency, but could integrate additional resources.	Neutral: Potential to increase or decrease peaks, depending on signals.	Neutral: No clear impact, highly case-dependent.	High: Enables shiftable loads and flexibility provision.	High: Very case-specific and tailored to user needs.	Low: Costly and slow to implement.	Low: capital intensive with generally only long-term return. Difficult to convince decision-makers.
Behind-the-meter investments	Neutral: Does not directly improve market efficiency, could integrate additional resources.	High: Significant potential for peak shaving and mitigating local stresses.	Neutral: No clear impact, highly case-dependent.	High: Enables shiftable loads and flexibility provision.	High: Very case-specific and tailored to user needs.	Low: High CAPEX and requires a significant degree of process integration.	Neutral: Moderately accepted, high investment costs but more potential for near-term returns.
Grid reinforcements	High: Reduces inefficiencies imposed by congestion.	High: Strongly supports table and efficient grid operation.	High: Helps industrial sites access reliable supply.	High: Increases ability to host flexible and variable loads.	High: Proportional to long-term flexibility, reliability, and efficiency gains.	Low: High costs, supply chain issues and public opposition hinder investment.	Low: Often opposed due to cost, disruption, or permitting.
Plug-and-play IT modules	Neutral: No direct effect.	Neutral: No direct effect.	Neutral: Only a small indirect effect through increasing flexibility provision.	High: Improves participation by simplifying integration.	High: Lightweight and targeted to the need.	Neutral: Feasible, requires the development of standards and harmonisation.	High: Generally well-accepted due to ease and scalability.
Standardized communication protocols	Neutral: No direct effect.	Neutral: No direct effect.	Neutral: Only a small indirect effect.	High: Crucial for interoperability and responsive flexibility.	High: Proportional with respect to coordination requirements.	Low: Requires coordination across actors and legacy system adaptation.	Low: Coordination costs and inertia to standardisation.

Company-internal levers	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Incremental investment approach	Neutral: No direct link to market efficiency improvements.	Neutral: No direct impact on grid operation.	Neutral: Slightly positive impact since it advances future-proof investments.	High: Enables gradual adoption of flexibility within firms.	High: Costs stay proportional to each site's risk, budget, and realized benefits.	High: Simple upgrades, start off with low complexity.	High: Aligns with firm's investment logic.
Mitigation strategies for flexibility risk	Neutral: No direct link to market efficiency improvements.	Neutral: No direct impact on grid operation.	Neutral: Does not directly improve company performance.	Neutral: Reduces risk, but does not in itself enable flexibility.	High: Well-targeted to a real internal barrier.	High: Mostly contractual instruments or operational precautions.	High: Likely welcomed by various levels as risk reduction.
Training & information sessions	Neutral: Improves awareness, but no structural market effect.	Neutral: No direct impact on grid operation.	Neutral: No clear direct impact.	Neutral: Only supportive; does not unlock flexibility on its own.	High: Light-touch and appropriate.	High: Easy to roll out internally.	Neutral: May be seen as low priority or redundant.
Adapted scheduling practices	Neutral: Does not affect market functioning, but may align firms better with prices.	Neutral: No direct impact on grid operation.	High: Can reduce energy costs by enhancing flexibility provision.	Neutral: Helps at site level, but not easily scalable.	High: Reasonable measure if aligned well with operations.	Low: Requires changes in routines and processes.	Low: May face internal resistance from (operational) staff.
Structured feedback loops	Neutral: No direct impact on market participation.	Neutral: No direct impact on grid operation.	Neutral: No clear direct impact.	Neutral: Not a direct driver of actual flexibility.	Neutral: Reasonable in scope, though limited direct impact.	Neutral: Depends on implementation. Added value should be clear.	Neutral: Stakeholders may see limited value.
Internal shadow pricing model	Neutral: Does not impact markets directly, may improve internal decisions.	Neutral: No direct impact on grid operation.	Neutral: No clear direct impact.	High: Helps firms internalise and act upon price signals.	High: Targets key barrier, case-specific.	Low: Requires modelling and internal capacity.	High: Non-intrusive, no impact on operations.

Company-internal levers	Electricity market efficiency	Grid operation	Industrial competitiveness	Effectiveness and scalability	Proportionality	Ease of implementation	Stakeholder acceptance
Energy procurement strategies	High: Enhances market responsiveness through better price signals.	Neutral: No direct impact on grid operations.	High: Helps manage energy cost and risk.	High: Directly enables flexible procurement behaviour.	High: Should be in line with other energy-related objectives.	Low: Requires complex contracts and market expertise.	Medium: Should align with energy priorities, but may face internal red tape issues.
Aligning company KPIs	Neutral: No direct impact on electricity markets.	Neutral: No direct impact on grid operations.	Neutral: Only indirect and very long-term link.	High: Can strongly influence internal priorities and actions.	High: Simple and focussed on internal alignment.	Neutral: Feasible, but may require some convincing.	Low: Resistance rather likely. Difficult to align with stakeholders.
Aligning employee bonusses	Neutral: No impact on electricity markets.	Neutral: No direct impact on grid operations.	Neutral: Does not change competitiveness.	Neutral: Modest effect, should be part of broader strategy.	High: Light and targeted incentive.	High: Technically easy to implement in HR systems.	Low: May be resisted as unfair or misaligned with current roles.
Integrating flexibility in strategic plans	Neutral: No direct market improvement, but can guide long-term readiness.	Neutral: No direct impact on grid operations.	High: Embeds flexibility into competitiveness planning.	High: Key to long-term flexibility provision.	High: Integrates into strategic cycles and avoids operational disruption.	Low: Requires leadership buy-in and cultural shift.	Neutral: Likely mixed reception; abstract for many staff.

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