Process model for aggregation of decentralized flexibility pools in Germany considering technical and market restrictions

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***Abstract*— With the expansion of renewable energy sources in Germany and the growing number of prosumers actively managing their consumption and feed-in, their potential to contribute to grid stability is increasing. In addition to expanding the transmission and distribution grids, leveraging flexibility in the low-voltage range - such as electric vehicles, heat pumps or household battery storage systems - could provide additional options for mitigating temporary congestions in the grid. This paper presents a conceptual approach for integrating small-scale flexibility resources into the redispatch process. The focus is on a potential supplementary, market-based redispatch model that may complement the existing cost-based mechanism. While aiming to explore how existing congestion management mechanisms could be applied for small-scale flexibilities, the study proposes a methodology for aligning technical and market restrictions when pooling small-scale flexibility resources. This proposal outlines a process from the end-customer level to the grid operator, intended to support the integration of small-scale flexibilities into the existing redispatch framework.**

Keywords: flexibility market, congestion management, aggregation model, flexibility pools, technical restrictions, market restrictions.

I. INTRODUCTION

A. *Challenges in grid operation and the potential of small-scale flexibilities*

With the ongoing expansion of renewable energy sources, electricity generation is increasingly shifting to decentralized plants. These plants are geographically distributed and highly dependent on weather conditions. As a result, electricity often needs to be transported over long distances, for example, from wind farms in northern Germany to consumption centers in the south. Simultaneously, the number of controllable electric devices, such as electric cars and heat pumps, is increasing, adding to the overall load on the electricity grid and further intensifying grid congestion challenges.

While many of these challenges are being addressed through the continuous expansion and reinforcement of the transmission and distribution grids, some grid congestion issues persist. Measures such as redispatch remain necessary to manage these congestions. Additional flexibility options could contribute to grid stability, particularly in southern Germany, where the demand for ramp-up capacity is expected to grow.

Small-scale flexibilities, such as electric vehicles, heat pumps and household battery storage, may enable short-term load shifting through targeted control. This could provide additional options for congestion management. Based on the scenario framework of the 2037 grid development plan [1], the German transmission system operators estimate that by 2037, installed capacities could reach 32 GW for electric vehicles, 7 GW for PV battery storage and 41 GW for heat pumps. However, the actual usable potential for grid operation is expected to be only a fraction of the total installed capacity. To harness the long-term potential of small-scale flexibilities, regulatory adjustments will be required. Additionally, suitable market structures, products, and operational processes must be developed and implemented. Addressing these issues at an early stage is essential to ensure that the electricity grid can meet future requirements efficiently.

B. *Cost-based redispatch approach and its limitations*

The current redispatch regime in Germany follows a cost-based approach, known as Redispatch 2.0. In general, generation plants and storage facilities with a nominal capacity of 100 kW or more are required to participate. Operators are compensated to ensure that redispatch measures remain cost-neutral for them [2]. While this model has proven effective for large-scale plants, it faces limitations when integrating loads,

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smaller storage systems and other small-scale flexibilities. These limitations stem from the diverse technologies, criteria and standards applicable to small-scale storage systems and flexible loads. Unlike conventional power plants, where flexibility costs can be clearly determined, decentralized flexibilities lack the necessary calculation model for reliable cost estimation, in particular regarding opportunity costs. Additionally, the primary function of these assets – such as electric vehicles, household battery storages or heat pumps – is not electricity generation, but meeting private or industrial needs. This fundamental difference complicates their integration into the cost-based redispatch framework.

Furthermore, EU legislation mandates the implementation of a market-based redispatch system. According to Regulation (EU) 2019/943 on the internal electricity market, Article 13 stipulates that such a system must be open to all types of generation, storage and loads [3]. The objective of this approach is to ensure fair and transparent utilization of flexibility while reducing congestion management costs.

C. *Market-based redispatch as complementary approach*

To address the requirements from the previous sections, an expansion of the existing cost-based redispatch framework to include market-based redispatch is currently under discussion. Studies such as "Redispatch 3.0: Regulatory framework, market and product design" [4] examine how this approach could be implemented. The combination of cost-based and market-based redispatch, often referred to as complementary redispatch, aims to leverage the strengths of both systems while optimizing congestion management costs.

Preliminary considerations suggest that this approach could enable the integration of smaller, flexible storage facilities and loads into the redispatch process while largely maintaining the existing Redispatch 2.0 mechanisms ([5], [6] and [7]). It is expected that such a model would create additional incentives for flexibility service providers while enhancing the efficiency of congestion management. One key advantage of this approach can be that the cost-based redispatch system would remain the primary mechanism, effectively serving as a cost cap for market-based redispatch.

The proposed complementary redispatch model aims to facilitate the integration of small-scale flexibilities into the existing redispatch process. It focuses on leveraging existing mechanisms and developing market-based mechanisms to support this integration. The proposal envisions a central role for flexibility service providers, who pool flexibilities from small-scale resources and offer them to grid operators. As an initial step, a qualitative study based on expert interviews was conducted to identify specific restrictions. By taking these restrictions into account and utilizing historical electricity demand, flexibility service providers are able to develop forecasting models for the utilization of flexibility resources. These forecasts enable the creation of flexibility pools, which are then offered to grid operators for congestion management. The primary focus of this paper is to describe the aggregation process for flexibility pools and how they can be offered via a flexibility platform.

II. METHODOLOGY

A. *Analysis of restrictions using semi-structured expert interviews*

This study employs semi-structured expert interviews as the primary method of data collection. As a qualitative approach, this method is well-suited for gaining insights from individuals with specialized knowledge, and given the limited number of experts in this emerging field, semi-structured interviews were considered particularly appropriate. [8]. The initial contact was established with TenneT TSO GmbH, which provided access to additional expert contacts based on current and past project collaborations. As a result, a total of five expert interviews were conducted. To ensure confidentiality, all interviews were anonymized in this study. The composition of the interview pool is summarized in Table 1.

TABLE I: THE EXPERTS INTERVIEWED FOR THIS STUDY[1]

Short	***IP I***	***IP II***	***IP III***	***IP IV***	***IP V***
Institution	FIM/ FIT	FfE	TenneT	TenneT	c.con

III. RESTRICTIONS

During the expert interviews, five key restrictions were identified that pose significant challenges to the integration of small-scale flexibility into the congestion management. These restrictions include: (A) Contracting period, (B) Buy-out options, (C) Catch-up effects, (D) Grid restrictions and (E) Flexibility limitations.

These challenges emerged consistently across multiple interviews, indicating their relevance and impact on the integration and utilization of small-scale flexibilities, as well as on the pooling process. However, given the current state of research, this list is not exhaustive. Rather, it represents a snapshot of existing challenges, which may evolve as market frameworks, regulations and technical capabilities develop. The identification of these restrictions serves to provide a structured perspective on the challenges which could be faced. Furthermore, these findings aim to enhance the understanding of the proposed process model and offer an initial basis for future discussions on regulatory and technical refinements.

TABLE II: RESTICTIONS IDENTIFIED BY THE EXPERTS

	Contracting period	***Buy-out options***	***Catch-up effects***	***Grid restrictions***	***Flexibility limitations***
IP I	X	X		X	X
IP II	X	X			X
IP III	X		X	X	X
IP IV	X	X	X	X	X
IP V	X	X		X	X

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[1] Abbreviations of the Institutes: FIM: Forschungsinstitut für Informationsmanagement; FIT: Fraunhofer-Institut für Angewandte Informationstechnik; FfE: Forschungsstelle für Energiewirtschaft e.V.; TenneT: TenneT TSO GmbH; c.con: c.con Management Consulting GmbH

B. *Contracting period*

The contracting period defines the duration and conditions under which flexibility service providers are contractually obligated to deliver flexibility. It specifies how long flexibility is provided and under what conditions it can be activated. In practice, the possible contracting periods may vary depending on the technology used to provide flexibility. Existing research indicates that larger-scale industrial flexibilities could be activated with activation periods of up to four hours per day. Decentralized household flexibilities such as electric vehicles, heat pumps and home storage systems are thought to exhibit higher variability in usage patterns, which could make their planning more complex. Grid operators require reliable flexibility to mitigate grid congestions issues. At the same time, flexibility service providers must ensure that they can consistently deliver the contracted flexibility without exposing themselves to unacceptable economic risks. A key challenge is that short-term contracting periods may make small-scale flexibility less attractive for grid operators. Conversely, long-term contracting periods pose a risk of non-availability, as small-scale flexibility resources may be unable to meet more long-term commitments due to variable usage patterns.

C. *Buy-out options*

Buy-out options allow flexibility service providers to withdraw from a previously agreed obligation to provide flexibility at short notice by paying a compensation fee. Similar to the contracting period, buy-out options are particularly relevant due to the variable availability of small-scale flexibilities. The ability to flexibly structure contractual obligations could encourage greater participation of small-scale flexibilities in a market-based redispatch model. However, buy-out options also present challenges from planning and reliability point of view. From a grid technology perspective, they may reduce the predictability of available flexibility, potentially impacting grid stability. Given these concerns, some studies suggest that such mechanisms should therefore be regulated between the flexibility service provider and the end customer rather than at the grid operation level. Grid operators rely on stable commitments to ensure that flexibility remains available when needed. This is particularly important for redispatch processes, where deviations can be difficult to compensate for.

Another challenge with buy-out options is the potential risk of strategic bidding behavior by market participants. This can occur when flexibility service providers are contracted to provide flexibility at a certain price but later opt to use the buy-out option when market prices rise, allowing them to sell the flexibility elsewhere at a higher price instead. One possible way of counteracting this is to introduce additional withdrawal fees for buy-out options. To effectively prevent strategic behavior, these withdrawal fees could be set at a level that makes reallocating flexibility to other markets economically unattractive in most cases. Alternatively, buy-out options could be granted only under specific conditions or be subject to a predefined usage limit to prevent excessive reliance on them. As previously mentioned, buy-out options might also pose a challenge for grid operators, as they may suddenly need to secure alternative flexibility resources, which might not be readily available or more expensive. Therefore buy-out options should be dealt with caution.

D. *Catch-up effects (Rebound effects)*

Catch-up effects refer to the subsequent energy demand that arises after a temporary reduction or shift in electricity consumption. These effects occur particularly in controllable loads such as heat pumps, electric vehicles, or industrial processes, where regular operation is interrupted due to their use as flexibility resources.

Catch-up effects can be particularly relevant in periods of high grid load, as they may influence the effectiveness of congestion management measures. For instance, if a large number of electric vehicles were to be simultaneously disconnected from the grid by a flexibility service provider, this could provide short-term relief. However, once these vehicles resume charging, a new load peak might emerge, which in some cases could approach or even exceed the original congestion levels. To mitigate these risks, accurate forecasting and active load management are required. This ensures that shifted loads do not reappear in an uncontrolled manner, leading to new grid congestions.

At the same time, it is important for end customers that the flexibility they provide does not negatively impact their primary usage, such as transportation needs for electric vehicles or heating requirements for heat pumps. Additionally, the economic attractiveness of offering flexibility must be maintained to ensure continued participation.

If a customer receives compensation for providing flexibility but faces higher electricity costs due to catch-up effects – such as increased energy consumption from heat pumps operating less efficiently or higher peak loads when recharging electric vehicles –this could reduce the attractiveness of participating in flexibility markets.

Therefore, from today’s perspective, the responsibility for mitigating catch-up effects should primarily lie with the flexibility service providers, as they are best positioned to implement effective forecasting and planning mechanisms. These mechanisms should not only account for the immediate activation of flexibility but also consider potential long-term cost implications for end customers.

E. *Grid restrictions (Grid constraints)*

Since small-scale flexibility resources are typically located at the low or medium voltage level, whereas redispatch measures may also be required at the high voltage level, a need for coordination between these different grid levels arises. In some cases, small-scale flexibility may be technically available but cannot be utilized due to local grid congestion. As a result, the grid operator at the higher voltage level may not be able to access the flexibility. A lack of coordination and standardization between grid operators further complicates the efficient use of flexibility. In particular, missing regulatory requirements and technical prerequisites hinder the optimal exchange of grid restrictions between grid operators. Since grid restrictions might have far-reaching effects – optimized communication and interface solutions are essential for improving data exchange between grid operators.

F. *Flexibility limitations*

Flexibility limitations refer to technical, economic or regulatory constraints that affect the availability and usability of small-scale flexibility. These limitations arise from the characteristics of different flexibility resources and the conditions under which they operate. For instance, while electric vehicles and household storage systems can contribute to flexibility, their availability is influenced by user behavior and charging patterns. Similarly, heat pumps face operational constraints, as their primary function is to maintain thermal comfort, which inherently limits their flexibility potential. For grid operators, the predictability and reliability of flexibility resources are crucial for effective congestion management. They depend on stable and plannable flexibility options, particularly for short-term interventions in the grid. However, if flexibility is only available for short or irregular periods, its usability may be significantly constraint. If flexibility can only be offered for short durations, financial incentives might not always be sufficient to ensure economically viable participation in the market. This could, in turn, reduce the economic appeal for end customers.

IV. RESULTS

Using the identified restrictions (Chapter II), a process model was developed. This model outlines the key steps for flexibility service providers to pool and provide flexibility while ensuring compliance with grid operator requirements. This process involves three key actors: the flexibility service provider, the grid operator and a flexibility platform, which serves as the central communication interface between them.

The following section describes the role of the flexibility service provider. The process begins with the registration of a new flexibility resource. If the resource is subject to different restrictions than an existing pool, a new pool is created. Otherwise, the new resource is integrated into an already established pool that meets the same requirements. Once the pools are formed, they are compared with the market design specifications set by grid operators. If discrepancies exist, the pools are adjusted accordingly. For instance, if the grid operators require a minimum contracting period of one hour, but a pool has a shorter duration, multiple pools may be combined to meet this requirement. This ensures that the pooled flexibility resources can be offered via a flexibility platform in compliance with grid operator needs. After the flexibility pool data is uploaded to the flexibility platform, the flexibility service provider awaits the awarding process for its flexibility tenders. The exact timing of the award process – whether it takes place a week in advance or even earlier – may depend on the specific market design proposal for complementary congestion management, which is not developed yet.

In the next step the flexibility platform bundles the flexibility pools of multiple flexibility service providers, provided they share the same framework conditions, such as location within the same region and have similar effectiveness on resolving the congestion issues. These bundles are then assigned to a single, relatively static data object for data exchange with grid operators. The available flexibility potential of these bundles may vary, depending on the flexibility pools submitted by the flexibility service providers.

The existing redispatch optimization process already utilizes comparable data objects to select suitable redispatch measures based on price and their effectiveness. Integrating the newly introduced bundles into this framework could enable a coordinated selection of cost-based and market-based redispatch measures. This alignment may allow for an optimization that takes both approaches into account, potentially improving overall efficiency. However, further analysis is required to validate how effectively these elements can be combined within operational processes. Ultimately, the redispatch optimization process selects specific measures for activation based on price and effectiveness.

This may include activating entire bundles or only portions of them, depending on system requirements and available flexibility. The activation signal is then transmitted to the flexibility platform, which unbundles the activation, assigns it to certain pools, and forwards it to the respective flexibility service providers.

The activation of the awarded pools takes place when the flexibility service provider receives an activation message from the flexibility platform. Upon receiving this message, the flexibility service provider initiates the activation of the corresponding flexibility resources to adjust their consumption or feed-in. Following activation, the flexibility service provider submits metering data to the flexibility platform, invoices the grid operator and compensates the flexibility providing end customers. This marks the completion of the process for using small-scale flexibility pools within the redispatch framework.

V. DISCUSSION

A. *Development of business models for end customers*

At present, no widely established business model exists for end customers to participate in congestion management in Germany. Uncertainties regarding compensation, as well as concerns about potential gaming risks and unintended congestion effects, may affect the attractiveness and acceptance of these solutions. A key challenge appears to be the lack of standardized monetary valuation for small-scale flexibilities. While traditional flexibility resources operate under defined compensation structures, there is currently no uniform pricing model for small-scale flexibilities. As a result, end customers or flexibility service providers considering participation may face challenges in estimating the potential financial benefit of offering flexibility resources. Beyond compensation-related uncertainties, the potential loss of convenience could also influence the willingness of end customers to participate in flexibility markets. If adjustments to their energy consumption patterns are perceived as disruptive, this may discourage engagement.

B. *Development of business models for flexibility service providers*

Flexibility service providers could play a key role in aggregating and marketing of flexibility. Various structural and technical challenges may influence their economic viability. One of the main challenges appears to be the lack of standardization in communication and data exchange processes between flexibility service providers, grid operators, and end customers in the context of congestion management. Without a standardized interface for data transmission, access to grid operators remains complex, which could limit the competitiveness and scalability of flexibility service providers. Another structural challenge may be the ongoing discussion about the differentiation between market-oriented aggregators and technical aggregators. Market-oriented aggregators primarily focus on trading flexibility in energy markets and participating in auctions, whereas technical aggregators are responsible for managing and optimizing flexibility at the household or company level. If synchronization between these two potential roles is not well coordinated, this could lead to inefficiencies in flexibility utilization, potentially reducing the reliability of flexibility provision for grid operators. Additionally, grid operators use cost-optimization tools to prioritize economically attractive flexibility offers. This may create competitive pressure for flexibility service providers to optimize their portfolio. Larger providers, benefiting from economies of scale, may have an advantage in this environment.

C. *Limitations and requirements for a market-based redispatch*

Currently, there are no clearly defined legal requirements for a standardized market model that provides grid operators, flexibility service providers and end customers with economic incentives to efficiently and reliably offer flexibility. While larger generation units and energy storages are already integrated into the German redispatch processes, the question remains how small-scale flexibility should be compensated to enable fair and sustainable market participation. One key challenge is finding a balance between preventing strategic bidding behavior, which could lead to inefficiencies, and avoiding excessively strict regulations that might discourage market participants. In the current redispatch framework in Germany, plant operators receive a compensation under a cost-based regime, which covers incurred expenses and lost revenues [2]. However, this may not be directly applicable to small-scale flexibilities, as the pricing structure set by grid operators does not necessarily cover the opportunity costs incurred by the end customers. A market-based regulation for decentralized flexibility appears therefore necessary. One possible approach is a complementary model that integrates both cost-based and market-based redispatch. To facilitate the integration of market-based flexibilities into this framework, pooling of small-scale flexibility resources appears necessary. Various pilot projects are currently exploring how small-scale flexibility can practically be incorporated into the congestion management. A clearly defined legal framework, developed in close coordination between policymakers, regulatory authorities, and market participants, is considered a key next step.

VI. CONCLUSION

The integration of small-scale flexibility into congestion management through pooling and bundling mechanisms appears to be a promising and feasible approach. An increasing number of small-scale flexibility resources, combined with the deployment of more advanced metering systems, may provide growing flexibility potential for congestion management. However, several constraints could affect the practical implementation and economic viability of these concepts. To explore this emerging field, this study conducted expert interviews to identify key challenges associated with integrating small-scale flexibility into the existing electricity market design. The main constraints identified include contracting periods, buy-out options, catch-up effects, grid restrictions, and flexibility restrictions. Contracting periods could pose a challenge, as long-term commitments create uncertainty for consumers, while short-term contracts might reduce planning reliability for grid operators. Buy-out options could offer economic flexibility for flexibility service providers but may also introduce uncertainties for grid operators regarding the reliability of flexibility resources. Catch-up effects might contribute to secondary load peaks, potentially complicating precise load shifting. Grid restrictions may require enhanced coordination between grid operators, while flexibility limitations could affect the availability and usability of small-scale flexibility resources under certain conditions.

Addressing these challenges requires a structured market design. Although the future framework of a market-based redispatch remains uncertain, various market design approaches are being explored to enable the utilization of small-scale flexibility.

This study proposes a process model that aims to align identified constraints and explore possibilities for integration. The process model outlines the roles of three key market participants: (1) The flexibility service provider, who may aggregate flexibility resources to pools to offer flexibility while balancing consumer needs and technical restrictions. (2) The flexibility platform, which could serve as an intermediary by bundling flexibility pools of multiple flexibility service providers into structured data objects for congestion management. (3) The grid operator, who may integrate these resources into congestion management strategies.

Beyond technical considerations, expert discussions also pointed to broader challenges, including the lack of established business models for both end customers and flexibility service providers, as well as regulatory uncertainties that remain unresolved. Future market design could be shaped by the increasing availability of market-based flexibilities, such as electrical vehicles, heat pumps, and household storage. These assets primarily serve consumption purposes but, under certain conditions, might also contribute to grid stabilization and congestion management. Further research and regulatory developments will be necessary to assess the feasibility and potential role of market-based flexibility within the redispatch process and its implications for grid stability.

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