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Long-term Contracts for Network-supportive Flexibility in Local Flexibility Markets

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Abstract

With an ongoing energy transition, the electric network is increasingly challenged. Handling congestion is a major responsibility of network operators. In recent years, market-based approaches to utilize network-supportive flexibility, especially local flexibility markets (LFMs), have been discussed as possible future development of congestion management processes. LFMs are a promising opportunity for the efficient, transparent and non-discriminatory integration of new flexibility options, in particular demand-side flexibility. Despite a wide body of supporting literature and several pilot implementations, there is still no common commitment to the concept of LFMs in the European Union. Here we address decision makers in the European energy economy, especially network operators, and discuss a possible flexibility product design using a methodological approach with four steps. First, we review the theoretical background of LFMs, considering both network operators' views and the possibility of demand response as a flexibility provider. Based on this review, we formulate an interim conclusion regarding requirements for flexibility product design in general. Second, using an existing framework, we propose a concrete, capacity-based, long-term flexibility product specification. Third, we discuss compliance between the defined requirements and the proposed product design to highlight the relevance of key design parameters and identify further research needs. Finally, we derive policy implications for network operators' decision makers regarding the implementation of LFMs.

Keywords:
demand side flexibility, local flexibility market, congestion management, flexibility product design

JEL classification: D47, L94, Q41

1. Introduction

With an ongoing energy transition the electric network is increasingly challenged, due to a growing share of renewable power plants' fluctuating generation and new electric loads. Local imbalances of generation and load can lead to bottlenecks in the electrical network, such as line congestion or over- and under-voltages; in the present work, these issues are conjointly called congestion. The handling of such congestion over different time horizons is a major responsibility of network operators. In the long term, congestion must be solved by network planning processes and network expansion; in the short term, different measures of congestion management can be used (Kumar et al., 2005). From an economic theory perspective, the most efficient congestion management approach in the short term is a nodal pricing electricity system, as the pricing mechanism of local marginal prices considers not only the concurrent balance of generation and demand but also the available network capacity and therefore prevents line congestion (Neuhoff et al., 2011; Hirth et al., 2018; Antonopoulos et al., 2020). However, there are several aspects of real markets that limit the benefits of this theoretical approach. The European Union (EU) thus follows a zonal electricity system approach, preferably with far-reaching pricing zones, for example, on a national level (European Commission, 2014). As a result, the electricity market outcome can lead to congestion situations that must be solved afterwards with different measures of congestion management, especially network-supportive flexibility.[1] In the following, network-supportive flexibility is defined as a modification of a previously planned baseline of electrical parameters (e.g., generation or consumption of power) in reaction to an external signal in order to resolve congestion in the electric network (ref. Villar et al., 2018; Höckner et al., 2020; Heilmann et al., 2020).

In recent years, the utilization of network-supportive flexibility has been frequently discussed in the academic literature and in the European energy sector (ref., e.g., Hillemacher et al., 2013; Hirth et al., 2018, 2019). The status quo comprises regulatory cost-based approaches, also referred to as cost-based redispatch, that use power plants' flexibility based on legal obligations and compensate for the cost of flexibility use (ref. German Association of Energy and Water Industries, 2018, for the German framework). Such a regulatory approach is intended to render the margin of the concerned asset economically equal to the situation without congestion. Following Hirth et al. (2019), we assume that a regulatory cost-based approach is an efficient measure, especially for large-scale power plants with known cost structure. Nevertheless, there is a huge flexibility potential in the field of demand-side flexibility that is currently nearly unused for the purpose of congestion management.

Demand-side flexibility, also referred to as demand response (DR), has been an important part of the European energy strategy for several years (European Commission, 2012; Euopean Commission, 2013). In Germany, for example, official planning scenarios for the expansion of the transmission network (ref. 50Hertz Transmission GmbH et al., 2022) project an increase in installed and feasible DR potential from a total of 6 GW in 2020 to 242 GW in 2045, mainly driven by battery storage, electric vehicles and heat pumps. Over the same time period, the installed capacity of conventional power plants is expected to decrease from 84 GW in 2020 to 48 GW in 2045, emphasizing the importance of considering DR as flexibility option.

However, there are various barriers to the realization of DR's flexibility potential (Coalition, 2017). The value of DR flexibility depends on technical restrictions; economic opportunities; and

[1] In nodal markets, the flexibility is also used as part of the market clearing process. In zonal markets, the flexibility is used as grid-supportive flexibility as the market clearing does not consider network constraints.

individual preferences, such as loss of comfort (Petersen et al., 2012). Due to the heterogeneity in the cost of small-scale flexibility, a regulatory cost-based approach to DR flexibility utilization cannot be efficiently realized.

An alternative approach is market-based utilization, especially when realized by a local flexibility market (LFM). In this paper, we define an LFM as a marketplace for long- or short-term trading of explicit flexibility products with the purpose of congestion management (ref., e.g., Ramos et al., 2016; Heilmann et al., 2020).[2] Network operators can use the LFM to procure flexibility for congestion management needs in addition to cost-based redispatch of large-scale generation units. The concept of LFMs is especially suitable for the utilization of DR as it enables flexibility pricing via individual bids based on the voluntary participation of potential providers. The techno-economical matching of an LFM's supply and demand, alongside consideration of regulatory flexibility provision, ensures efficient short-term flexibility usage (Heilmann et al., 2021). Therefore, LFM can potentially improve the overall efficiency of congestion management.[3]

Although there is a broad literature basis supporting LFM and several pilot implementations, there is still no common commitment to the concept of LFM in the EU. One main challenge to the implementation of LFM is the definition of appropriate flexibility products to serve as a basis for the identification and valuation of available flexibility (Heilmann et al., 2020). Intuitively, the design of flexibility products is similar to that of energy products of the short-term wholesale market. Still, with such a short-term product design, various studies point out the opportunity of undesired strategic behavior (see Section 2.1). In addition, various requirements of network operators and flexibility providers must be considered. This paper contributes to the debate on suitable flexibility product design. We address decision makers in the European energy economy, especially network operators, who want to develop future congestion management approaches. We focus on one particular flexibility product proposal based on capacity-based, long-term contracts. Our methodological approach contains four steps that define the structure of this paper:

1 We review the theoretical background of LFMs, considering both network operators' perspective and the potential of DR as a flexibility provider. We use our findings to formulate an interim conclusion regarding requirements for flexibility product design in general (Section 2).

2 Using an existing framework by Heilmann et al. (2020), we propose a concrete, capacity-based, long-term flexibility product specification (Section 3).

3 We discuss the compliance between the defined requirements and the proposed product design to highlight the relevance of key design parameters and identify further research needs (Section 4).

4 We derive policy implications for network operators' decision makers regarding the implementation of LFMs (Section 5).

[2]Note, that different terms, such as regional flexibility market, market-based congestion management or market-based redispatch are used as synonyms in this context.

[3]The idea of market-based congestion management also aligns with the legal framework of the EU (European Commission, 2019a,b).

2. Theoretical background

2.1. Local flexibility markets (LFMs) as a congestion management approach

In the ongoing debate on how to most efficiently solve congestion in the electricity system, researchers have frequently concluded that nodal pricing is the best approach from an economic and theoretical perspective (ref., e.g., de Vries and Hakvoort, 2002; Kumar et al., 2005; Green, 2007; Dijk and Willems, 2011; Neuhoff et al., 2011; Hirth et al., 2018; Antonopoulos et al., 2020). However, it can be argued in favor of larger bidding zones to foster liquid markets and stable long-term price signals. Additionally, with the aim of creating a European internal energy market, participating nations tend to prefer large market zones (European Commission, 2014). LFM is a market-based congestion management approach that has been investigated in several academic studies and prototypical implementations in recent years. Radecke et al. (2019) and Anaya and Pollitt (2020b,a) provide reviews of European LFM prototypes, including the analysis of benefits and disadvantages for relevant stakeholders. A more detailed discussion of individual projects is provided, for example, by Schittekatte and Meeus (2020), Heilmann et al. (2020) and Dronne et al. (2021b). Different model-based studies indicate that LFMs can be suitable for short-term congestion management (ref., e.g., Torbaghan et al., 2016; Olivella-Rosell et al., 2018b,a; Esmat et al., 2018; Shen et al., 2019; Heilmann et al., 2021; Schmitt et al., 2021). In this context, Jin et al. (2020) provide a comprehensive review of LFM, analyzing concepts, models and clearing methods. Additional studies argue that long-term contracted flexibility can be the basis for long-term decision making that governs flexibility use and network investments (Spiliotis et al., 2016; frontier economics, 2020). Dronne et al. (2021a) argue that long-term capacity auctions can decrease uncertainties for both network operators and flexibility providers and therefore incentivize flexibility investments. In summary, many studies have discussed and demonstrated the functionality of LFMs and have argued that a market-based valuation of flexibility is a promising approach for future congestion management. Two main advantages are evident:

- LFMs allow network operators to leverage different technologies' flexibility, including DR.
- Because LFMs contain a transparent winner-determination mechanism, they ensure optimal techno-economic flexibility selection.

Although there is a broad literature basis and several pilot implementations, there is still no common commitment to the concept of LFM in the EU. This lack of adoption may be driven by several factors. First, existing congestion management processes, which focus on electricity generation assets, may be currently sufficient and may continue to be so for the next few years. Second, there is an ongoing debate on the concept of market-based congestion management in general that considers the possibility for strategic bidding behavior of flexibility suppliers. Two main classes of strategic behavior can be differentiated (Klempp et al., 2020b,c):

- **The execution of market power:** As LFMs generally have smaller market zones than a zonal electricity market on a national level, the number of potential bidders and, consequently, the competition are typically reduced. The potential for individual bidders to exert market power therefore increases, and these bidders may be able to influence an LFM's outcome to achieve higher market prices and maximize their profit.
- **Taking advantage of market-design inconsistency:** If the price signal of the LFM can be compared directly to the price signal of the energy market, undesired strategic bidding behavior, referred to as "Increase-Decrease-Game" (INC-DEC) can occur (Hirth et al., 2019).

Both problems can occur independently but may exacerbate each other. Hirth et al. (2019) and Hirth and Schlecht (2020) discuss the possibility of INC-DEC in a market-based congestion management approach for the example of Germany, concluding that LFMs should not be implemented. In addition, different economic model-based investigations demonstrate that market-based congestion management can lead to inefficiency, especially in comparison to a nodal electricity system (ref., e.g., Holmberg and Lazarczyk, 2015; Sarfati et al., 2018a,b, 2019). Sarfati and Holmberg (2020) and Grimm et al. (2020) discuss different approaches to reduce the INC-DEC problem by adjusting the market clearing approach.

As basis for the discussion in Section 3.1 and Section 4, here we provide insight into the mechanism of INC-DEC in the context of DR following the existing approaches described in literature. The following explanation assumes that the structure of flexibility products is similar to spot market energy products. In Section 3.2, we provide a product design proposal that does not follow this assumption and demonstrate that INC-DEC can be mitigated. In general, two zones of a schematic congestion situation, the "High Generation/Low Load" case and the "Low Generation/ High Load" case, can be differentiated. On the premise of a balanced overall system, both cases occur at the same time in different network zones (ref. Hirth and Schlecht, 2020, for a two-node network example). Due to different load and generation situations in the network zones that lead to congestion between zones, different LFM prices can be expected that are in theory based on the local marginal price of the concerned network node (Hirth and Schlecht, 2020; Hirth et al., 2019). To understand the INC-DEC strategy, it is expedient to separately consider both situations:

- In "high generation/low load" network areas, the LFM price is expected to be lower than in the spot market. Therefore, flexible consumers may not buy the energy they need from the spot market but instead provide the flexibility of higher consumption in the LFM for a lower energy price.[4]
- In "low generation/high load" network areas, the LFM price is expected to be higher than that of the spot market. Therefore, flexible consumers that technically avoid consuming energy can buy energy at the sport market and then sell the flexibility to reduce consumption in the LFM.

In both specifications of the INC-DEC strategy, the planned baseline of consumption is not adjusted and therefore no actual flexibility is provided. The incentive of this strategy results from the price differences between the spot market and LFM. In addition, the consistent INC-DEC behavior of market participants increases the demand for flexibility and therefore is not a matter of market power (Hirth et al., 2019). The main assumption for the implementation of INC-DEC is the availability of valid information about network congestion and spot market and LFM prices. We assume that this information –if not publicly available– can be anticipated with suitable forecast models (ref., e.g., Heilmann, 2021). Nevertheless, following (Klempp et al., 2020b) and (Klempp et al., 2020c), we state that every form of strategic bidding behavior can be mitigated by suitable market rules in combination with monitoring and a purposeful flexibility product design. The prevention of INC-DEC is one main focus of this paper.

In addition to the possibilities of flexibility providers' strategic behavior, Buchmann (2020) notes that network operators can also potentially act strategically or discriminatorily when selecting flexibility, withholding network investment and sharing information on future flexibility

[4]In principle, negative prices are also thinkable. In this case, a flexible asset gets paid for consuming energy.

requirements. In this context, an appropriate institutional design and regulatory framework targeting network operators must be considered in LFM design (Buchmann, 2020).

In summary, although the possibility of strategic bidding behavior should be considered, LFM is a promising approach for the future development of congestion management in zonal electricity markets.

2.2. Network operators as demand-side LFM participants

A prerequisite for the extensive implementation of LFMs in Europe is improvement in cost-efficiency for both individual network operators and the overall system. Various studies have analyzed network operators' requirements for LFMs (ref, e.g., Klempp et al., 2020a; Heilmann et al., 2020, 2021; Villar et al., 2018; European Distribution System Operators for Smart Grids, 2018):

- An LFM must decrease operational costs of congestion management and enable network operators to select flexibility options that are suitable for resolving congestion more efficiently than the alternative measures.
- Technical effectiveness and economic efficiency must be ensured. Therefore, a flexibility product must contain a local component to serve as the basis for a techno-economic evaluation. In addition, aspects of reliability should be considered in the product design.
- A regulatory fallback option besides the LFM is obligatory for a secure network operation in case of emergencies.
- A standardized coordination between different network areas and levels is necessary. This requirement has various aspects. First, in line with the requirement of improving cost-efficiency, the overall flexibility required should be minimized. Flexibility in the distribution network must therefore be available for transmission networks' requirements. Second, the usage of flexibility must not result in new congestion in other network areas.
- An LFM should consider the existing congestion management processes to minimize transaction costs for the implementation and operation of an LFM as a congestion management measure. These costs include monitoring and documentation.

Techno-economic optimization of the used flexibility and coordination between different network operators form the basis for the operational efficiency of the overall system (Villar et al., 2018; European Distribution System Operators for Smart Grids, 2018). Still, the operational efficiency can only be ensured if interference between the LFM and existing electricity markets is limited. The mitigation of INC-DEC is a major task of LFM design. Finally, the long-term perspective (i.e., investment decisions for network expansion), should be addressed by providing a price signal as a basis for decision making (ref., e.g., Spiliotis et al., 2016; frontier economics, 2020).

2.3. Demand response as flexibility provision

Though it is important to consider the requirements of network operators, this section analyzes flexibility providers' requirements, focusing on the integration of DR. There is a broad discussion in the academic and semi-academic literature that covers various DR use cases in different fields.[5] The application of DR can affect every aspect of an electricity system, including the wholesale market, congestion management, system balancing and system adequacy (Liu, 2017; Hermans et al.; Coalition, 2017). Due to the broad range of use cases, many general advantages of DR can be named: an improved integration of renewable generation, efficient utilization of network and generation capacities, lower and more stable market prices, control of market power and economic benefits for end consumers (Paterakis et al., 2017).

Approaches to DR implementation can be classified into price-based and incentive-based programs, respectively implicit and explicit flexibility (Weck et al., 2017; Paterakis et al., 2017; Coalition, 2017). With the focus on the provision of network-supportive flexibility in LFM, DR has to be interpreted as explicit flexibility product (ref. Heilmann et al., 2020). Nevertheless, the different opportunities of marketing DR must be considered due to two reasons:

- Different DR marketing possibilities should be interpreted as competitive. The physical effect of flexibility can only be provided to one market at any given time.
- Flexibility providers will generally try to maximize their profit. Notably, they will select the marketing option with the highest individual economic benefit. Based on this consideration, strategic bidding behavior must be anticipated.

Although there is considerable potential for system benefits, DR approaches are still not state of the art in the member states of the EU, at least not for every use case (Coalition, 2017). Various studies that discuss general DR barriers, often in connection with practical examples, identify the following inhibiting factors (ref., e.g., Hermans et al.; Lampropoulos et al., 2018; Annala et al., 2018a; Paterakis et al., 2017; Coalition, 2017; Weck et al., 2017; Bertoldi et al., 2016; Warren, 2015):

- **Regulatory framework:** the general energy system design and legislation strongly influences the possibilities and acceptance of DR. The regulatory framework is the basis for organizational and economic considerations.
- **Organization issues:** high access requirements, missing standardization and unclear definitions of market roles and responsibilities can lead to significant market entry barriers.
- **Economic issues:** expected individual benefits are often too low for DR marketing or even investment decisions.
- **Technical issues:** some fields of application lack appropriate technology and sufficient automation.
- **Socioeconomic issues:** willingness to participate, especially in explicit flexibility programs, is an individual decision that is influenced by different factors. These factors can be economic or technical, but also may contain exclusion criteria, such as a perceived reduced level of autonomy, lack of understanding, concerns about data privacy et cetera.

[5] Various studies have provided reviews of business models (Behrangrad, 2015), technical aspects (Siano, 2014), the electricity market's perspective (Sousa and Soares, 2020) and modeling approaches (Boßmann and Eser, 2016) in the context of DR. In addition, practical examples, often in connection with policy approaches and regulatory frameworks, have been reviewed, e.g., by Torriti et al. (2010); Bertoldi et al. (2016); Coalition (2017); Paterakis et al. (2017); Annala et al. (2018a) and Annala et al. (2018b).

The intuitive conclusion regarding DR requirements for an LFM and flexibility product design is that the mentioned barriers must be reduced as much as possible. One prerequisite is a regulatory framework that ensures transparency and absence of discrimination to provide a level playing field for all market participants. Standardized rules and flexibility products for the LFM must be defined, as these form the basis for potential flexibility providers to plan and bid. Each potential flexibility provider should in principle be able to place a bid on the LFM, but the individual price could be particularly high. The price of flexibility depends on technical restrictions, economic opportunities and individual preferences and comfort demands (Petersen et al., 2012).

To decrease market entry barriers in energy markets, it is necessary for many small flexible assets to be pooled by third-party "aggregators" that provide the service of flexibility marketing. The aggregation of small-scale flexibility provides two main advantages (ref., e.g, Coalition, 2017; Eurelectric, 2014). First, organizational efforts from asset owners are decreased and the efficiency of the overall marketing processes are increased. Second, an aggregator can improve the reliability of flexibility provision as the probabilistic forecast of availability is improved by a growing number of individual assets and different technologies (this result is known as the portfolio effect). Nevertheless, aggregators also face the general barriers of DR, in particular the restrictions based on individual preferences and technical limits as well as economic aspects. In a contract between aggregators and owners of flexible assets, individual preferences must also be considered. The aggregator must therefore consider the restrictions of flexibility provision for the determination of available flexibility as well as the vast heterogeneity in this field.

2.4. Interim conclusion – requirements for flexibility product design

Market-based approaches, especially LFMs, are a promising opportunity for the efficient, transparent and non-discriminatory integration of DR into congestion management processes. Existing mechanisms of regulatory congestion management should not replaced but rather complemented by LFMs. The combination of regulatory cost-based congestion management and LFMs as market-based approach provides potential cost reduction as it utilizes new flexibility considering the existing options as benchmark (Klempp et al., 2020b,c). Nevertheless, a review of existing literature on LFM design challenges and DR flexibility provision stresses the non-trivial challenges associated with implementing LFMs. One frequently mentioned aspect is that regulatory and legal frameworks hinder the development of LFMs and DR. Still, EU legislation principally supports both DR and LFM (European Commission, 2012; Euopean Commission, 2013; European Commission, 2019b). Therefore, for the remainder of this paper, we assume that legislation at an individual national level does not hinder the implementation of LFM. Based on this assumption, the most important task for practical application of DR in LFMs is the design of flexibility products (Heilmann et al., 2020). An explicit product design is the basis for planning and marketing decisions, including bidding and pricing the provided flexibility, for flexibility provision as well as congestion management planning of network operators.

Concluding the theoretical overview, we present three overarching targets for the design of flexibility products:

- **(i) The electricity system's efficiency must be ensured.** The overall costs of congestion management must decrease in comparison with alternative measures. This minimization includes mitigating misplaced incentives for undesired strategic behavior to avoid negative implications on other electricity markets that may exceed the advantages for the congestion management.

(ii) **Short-term preferences of network operators as well as potential flexibility suppliers must be considered and balanced.** From the network operator's perspective, these preferences mainly comprise technical issues that ensure reliable, effective and efficient network-supportive flexibility use and enable low transaction costs. From potential flexibility suppliers' point of view, suitable product design must decrease the organizational, technical, economic and socioeconomic barriers and increase profits margins while minimizing transaction costs (Bertoldi et al., 2016; Hermans et al.).

(iii) **Long-term decision making should be supported.** The implemented flexibility products should provide a basis not only for short-term operational planning but also for middle- to long-term decision making, including investment decisions made by all participants.[6] Network operators may evaluate the usage of flexibility in comparison to network expansion. Flexibility providers may value investments that increase the potential for flexibility.

The following section provides a proposal for a capacity-based, long-term flexibility product design. The accordance of the product design with the three defined targets is discussed afterwards.

3. Proposing a capacity-based, long-term flexibility product

3.1. Conceptual classification

The intuitive flexibility product design is a day-ahead energy product that follows the product design of other short-term energy markets to achieve a high degree of interoperability between different markets and processes. Different LFM pilots use such short-term energy products (e.g., on the basis of quarter-hour time slices) in their prototypical implementations (ref., e.g., Heilmann et al., 2020; Anaya and Pollitt, 2020a). Still, as discussed in Section 2.1, such product design results in nodal price signals as opportunity prices parallel to the zonal spot market price. In consequence, INC-DEC behavior must be expected that may causes market distortions and increases the amount of flexibility needed (Hirth and Schlecht, 2020; Hirth et al., 2019). Therefore, we propose an adaption to the product design that includes the following four aspects.

First, network operators should have the opportunity to contract flexible capacity that can be requested only if necessary. Such capacity-based electricity contracts are referred to as call options (Hull, 2012). The seller of the option does not know ex ante if flexibility will be requested. Therefore, a call option contains a capacity price, also referred to as a premium, for the provision of flexible capacity and a strike price for the energy, if flexibility is requested.

The call options approach supports the requirements of network operators, but does not generally mitigate the possibility of INC-DEC, as the strike price can also be interpreted as a price signal parallel to the zonal spot market. Therefore, secondly, we suggest regulating the strike price by setting it to the actual intraday spot market price of the affected quarter hour. In consequence, the parallel price signals –strike price and spot market price– are the same and therefore do not create an opportunity for INC-DEC. The regulated strike price does not contain an incentive for the flexibility provider to participate on the LFM as the revenue potential is the same as at the spot market. Therefore, flexibility provider must generate profit with the capacity premium.

Following a day-ahead contraction of flexible capacity, it is still possible to use an INC-DEC strategy to increase the amount of flexibility needed.[7] In consequence, flexibility providers are

[6]For such investment decisions, stable price signals are beneficial.

[7]In Europe, determining the amount of network-supportive flexibility is connected to day-ahead trading processes.

incentivized to artificially increase flexibility demand to achieve a capacity premium. To mitigate this incentive, thirdly, we suggest expanding the bidding blocks of the call options and contracting the flexibility before the day-ahead market result. With this long-term contraction approach, flexibility providers have no incentive to directly influence the short-term need for flexibility.[8] Nevertheless, the assessment of the available flexibility and the calculation of the premium become more difficult as the time horizon of the bidding block increases. Flexibility providers must estimate the impact of the flexibility provision without knowing the exact time and strike price ex ante. In addition, this solution also makes it more difficult for network operators to procure the exact amount of flexibility needed.

With the discussed difficulties, we suggest a final necessary aspect of the flexibility product design to address the individual short-term preferences of the market participants. The definition of network operators' technical requirements and flexibility suppliers' restrictions can help to overcome the trade-off between individual planning aspects, reliability of flexibility provision and the possibility of strategic bidding behavior. The following section contains the detailed proposal of a flexibility product that follows the capacity-based, long-term concept discussed above.

3.2. Flexibility product specification

Heilmann et al. (2020) provide a flexibility product design framework that is suitable for a comprehensible description of the technical and trading dimensions of a flexibility product.[9] The framework is organized into four stages with different levels of abstraction. In total, 22 different parameters can be used to describe a product specification in detail. We follow this framework to present a concrete and explicit proposal for a capacity-based, long-term product. We thus specify all 22 parameters and discuss their influence on the network operators as well as flexibility providers' requirements and potential trade-offs. To highlight the most relevant issues of our proposal, we have slightly adjusted the structure of the original framework (see Figure 1). First, we describe the technical core product and its relation to communication aspects. The core product is the basis for the main design choices of the product, namely the temporal aspects of the product and organization as well as the technical rules. The trading-related rules –especially considerations related to remuneration– and aspects of auction design complete the design space of the product. The adaption of the framework is summarized in Figure 1.

We provide a textual discussion of all parameters in Sections 3.2.1 - 3.2.4, followed by a tabular summary in Section 3.2.5. The provided product proposal includes possible specifications for a capacity-based, long-term flexibility product as well as a rough proposal of an auction design. Still, details of individual design parameters can in principal be changed if it is technically or economically reasonable. The proposal forms the basis for the discussion in Section 4.

3.2.1. Technical basis: core product with spatial specification and communication aspects

The flexibility product's technical core (*technical good* and *direction*) contains the adjustment – positive or negative– of electrical power in comparison to a defined baseline and with information on the local information on the network connection of the flexibility providing asset to the network (Heilmann et al., 2020). This technical core describes the actual commodity of the product. To

[8]In theory, it is still possible to influence the amount of flexibility needed using a mid- to long-term INC-DEC strategy. Still, the effort and risk would be much higher than those of the short-term INC-DEC strategy.

[9]The regulatory framework is not explicitly considered, as it strongly depends on national legislation. We follow this approach and assume that the barriers framework does not hinder the concept of LFM.

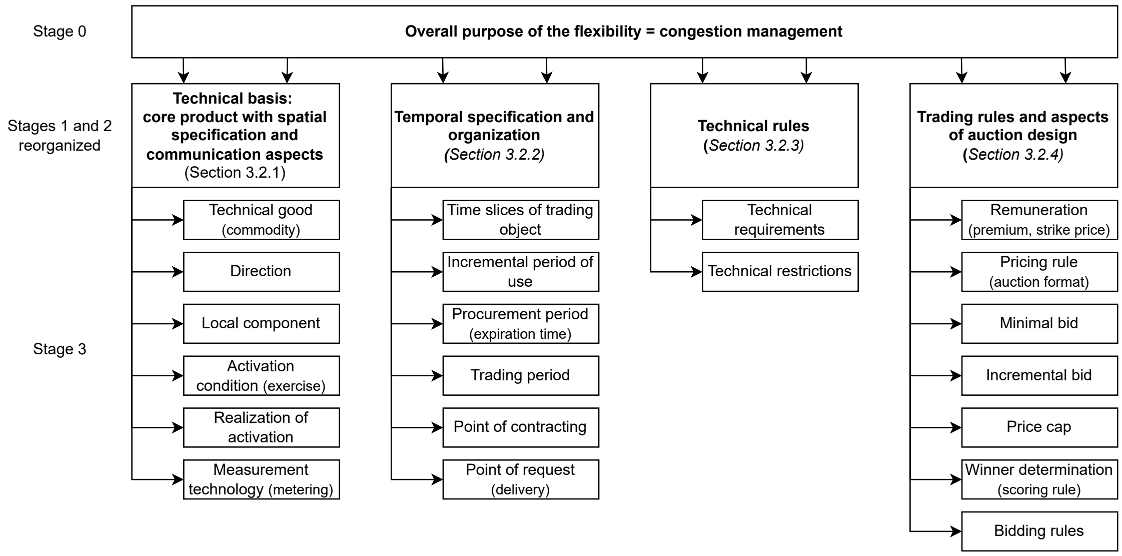

Figure 1: Flexibility product design framework by Heilmann et al. (2020), with reorganized Stages 1 and 2

provide a high level of planning capability, the commodity must be delivered as defined technical power, if requested by the network operator (*activation condition*).[10] The *realization of activation* contains the submission of the target value that can be realized in different technical implementations. The used *measurement technology*, including information and communication infrastructure, must contain a metering concept that is suitable for collecting and processing energy data at a resolution at least equal to the increment of flexibility provision and in close to real-time.

3.2.2. Temporal specification and organization

The first temporal parameter is the *time slice of the trading object* that describes the bidding block of the option. As discussed in Section 3.1,the time slice must in general be longer than the time slices of energy trading in spot markets (typically one hour or one quarter-hour). The definition of this parameter must consider not only short-term planning aspects but also the minimization of long-term risk and transaction costs. We suggest a time slice of one week.

The second temporal parameter, *incremental period of use*, characterizes the time span of flexibility delivery and therefore also describes a standardized metering period of a market. This time span must be in line with the increment of the energy-only market as well as with optional measures of congestion management to support process compatibility and decrease transaction cost. Therefore, we suggest one quarter-hour as the incremental period of use.

Various parameters of temporal organization describe the temporal patterns of the exemplary trading process.[11] The *procurement period* describes the expiration time of the options and therefore determines how many time slices of the product can be procured by the network operators at once. The *trading period* contains the time span of actual trading activities. With one-week time slices, we suggest that the procurement period should only contain one time slice and be

[10] An optional activation condition would be a quota of the concerned power.

[11] The description of the trading process is intended to provide a consistent product proposal. Nevertheless, real-world marketplaces can differ from the suggested patterns.

organized in one-week auctions ending one week before the beginning of the relevant time slice. The *point of contracting*, describing the time when the flexibility product is traded, is at the end of the procurement auction. The *point of flexibility request* determines when the flexibility delivery is requested. It must be in line with the existing measures of congestion management to provide process compatibility. On the other hand, the reaction time of flexibility providers should be considered. A high degree of automation and the possibility of remote control can support the realization of short activation times. Figure 2 summarizes all temporal parameters discussed.

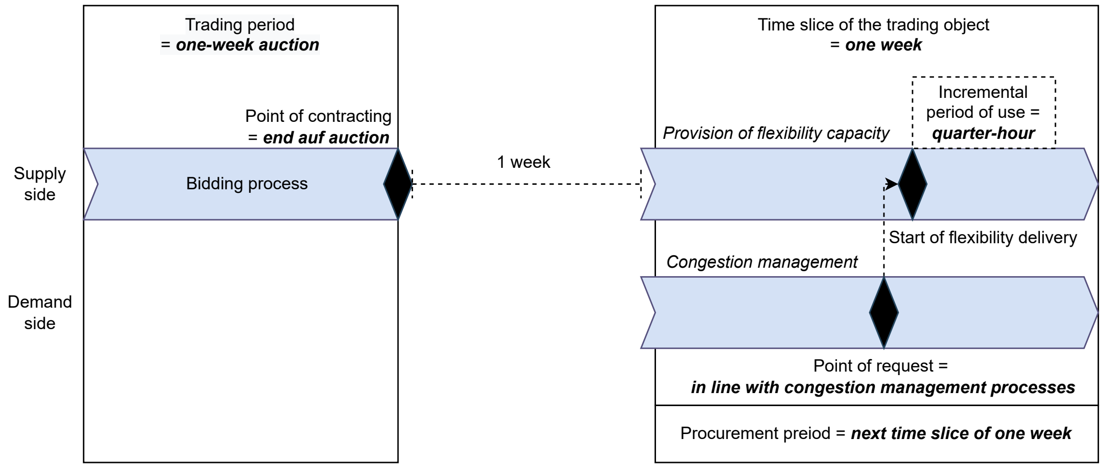

Figure 2: Temporal aspects of the product proposal

3.2.3. Technical rules

Technical rules can capture the preferences of the network operators (*technical requirements*) and of the flexibility suppliers (*technical restrictions*). A detailed specification of such rules can effectively determine which technology is able to provide a specific flexibility product. On the other hand, technical restrictions as well as limitations of different stakeholders' comfort can also be considered to reduce market entry barriers. The design of technical rules with a quasi-infinite design space can be interpreted as the most challenging design task as it must optimize different trade-offs:

- **Reliability versus adaptability and restrictions of flexibility provision:** The main technical requirement of network operators is the secure procurement of flexibility with a level of reliability in order to reliably solve congestion. From the supplier's perspective, the short-term adaption of available flexibility is desirable because the permanently secure maintenance of flexible power causes higher costs.

- **Technology-neutral standardization versus technology-specific individualization of flexibility products:** A high level of standardization is generally preferable as it reduces the complexity of the market processes and therefore decreases transaction costs for all involved parties. However, such standardization can lead to significant technical barriers for individual technologies and therefore reduce the amount of flexibility available or increase the price of this flexibility.

Reliability is a core parameter of a network operator's planning processes. Therefore, the target value of the flexibility's availability should be defined as nearly 100 percent of the assured capacity. To provide flexibility capacity with the desired reliability, an individual flexibility supplier must forecast the availability patterns of their assets. As discussed in Section 2.3, it can be assumed that small-scale flexibility options (e.g., private households' assets) are aggregated by a third-party marketer. Nevertheless, the available flexibility is dependent on the technical limits and individual behavior and preferences that can change in the short-term. Therefore, a forecast of available flexibility over the pursued time horizon is generally complicated by high uncertainty. Technical restrictions can help to weaken this uncertainty by defining exception from the above discussed assured availability. We suggest the implementation of comprehensible technical restrictions, such as a maximum amount of flexible energy per day, minimum time between two flexibility requests and the possibility to veto individual flexibility requests (e.g., no more than one request per time slice). However, as mentioned, the trade-off between availability requirements and reliability has to be evaluated.

3.2.4. Trading rules and aspects of auction design

The last aspect of the flexibility product design framework is the trading dimension.[12] Trading related rules and aspects of auction design define the bidding and settlement processes within the LFM. The temporal aspects of trading, namely the trading and procurement periods as well as the points of contracting and request, are discussed in Section 3.2.2. The most important trading-related parameters in the context of capacity-based, long-term products *remuneration* in connection with a *pricing rule*. As discussed in Section 3.1, we propose a hybrid remuneration and pricing system of the flexibility option with two elements:

(i) **Competitive capacity payment (premium) for the maintenance of the flexible power.** The amount of this payment is determined by the output of the procurement auction as a pay-as-cleared price. Therefore, the capacity payment provides the opportunity for flexibility suppliers to generate profit margins over the product time slice of one month and must cover all potential costs of capacity provision.

(ii) **Regulated energy payments (strike price) for flexibility delivery.** From the system's perspective, the value of short-term energy is priced by the spot markets. To provide short-term price consistency, the LFM's energy payments must be coupled with the spot market prices.[13] The short-term delivery of DR flexibility can be either the increase or reduction of a load. A load reduction must be paid using the intraday spot market price, and an increased load must pay this price.

As the energy payments are the same as for intraday marketing of the flexibility profit margins can theoretically be generated, but do not necessarily have to be. Profit margins are generated if the value of a reduced load is lower than the regulated energy price or if the value of an increased load is higher than the regulated energy price. The calculation of bids for flexible capacity payments must consider all costs of flexibility provision, including the possibility for negative profit margins that occur due to energy payments.

[12]The trading dimension complements the technical dimension of the framework to provide a consistent product design (Heilmann et al., 2020).

[13]In the case of German market design, we suggest using the energy-weighted price of the last hour of intraday continuous trading (ID1) to reflect the price including the latest information for price formation.

The framework contains additional possibilities for the specification of trading rules, especially *minimal and incremental bids* as well as the possibility of *price caps*. We suggest that it is not necessary to define these parameters in order to meet the defined product design targets.[14] The *winner determination* describes the complex techno-economic optimization problem the network operators must solve to determine the assets and prices for flexibility procurement. Finally, the *bidding rules* describe the organizational framework of the auction. The rules should be clearly defined, but not too complex, to minimize market entry barriers. We suggest that placing, changing and deleting bids should generally be possible during the trading period of the auction but not after the winner determination and acceptance of bids.

3.2.5. Summary of the product design proposal

Sections 3.2.1 - 3.2.4 contain the specification of all 22 parameters of the framework by Heilmann et al. (2020) to define a concrete, capacity-based, long-term flexibility product design. The design choices of the discussed parameters have varying degrees of freedom. We characterize each parameter on a spectrum ranging from “low” to “high” degree of freedom to describe the respective design space. An exception is the commodity itself (the technical good in connection with the direction) that, due to the nature of the problem, is always an electric power that can be positive or negative and therefore has no degree of freedom. Parameters with a low degree of freedom are relatively fixed in their basic characteristics, but details can still be defined. Parameters with a high degree of freedom can be changed considerably and often influence other dependent parameters.[15] Table 1 provides an overview of all 22 specified design parameters with the characterization of the design space.

[14] The hybrid congestion management approach does implicitly contain a price cap due to the regulated cost-based flexibility options of power plants

[15] An example of such a profound re-design is the temporal structure of the flexibility product. If the time slice of the trading object is changed from the proposal (one week), it is necessary to re-design the procurement period and may be useful to also reconsider the trading period and organization.

Table 1: Summary of product specification

Category	Design parameter	Specification	Degree of freedom
Technical basis (Section 3.2.1)	Technical good	Electric power	none
	Direction	Positive or negative	none
	Local component	Local information of network connection	low
	Activation condition	Direct technical value of flexible load	low
	Realization of activation	Different technical implementations possible	medium
	Measurement technology	Suitable for collection and processing of energy data in the resolution of incremental period of use	medium
Temporal aspects (Section 3.2.2)	Time slices of trading object	One week	medium
	Incremental period of use	Quarter hour	low
	Procurement period	One week (next time slice)	medium
	Trading period	One-week auctions ending one week before next procurement period	high
	Point of contracting	End of the procurement auction	high
	Point of request	Dependent on existing congestion management measures	low
Technical rules (Section 3.2.3)	Technical requirements	Degree of reliability	high
	Technical restrictions	Exceptions of availability: maximum requests per day, minimum time between requests, possibility to veto	high
Trading rules and auction design (Section 3.2.4)	Remuneration	Competitive capacity payment (premium) and regulated energy payment (strike price)	medium
	Pricing rule	Pay-as-cleared for capacity payment (premium) in remuneration auction; regulated energy payment (strike price) depending on intraday spot market prices	medium
	Minimal bid	Not defined	low
	Incremental bid	Not defined	low
	Price cap	Not defined	medium
	Winner determination	Techno-economic optimization, depending on procurement strategy of network operators	high
	Bidding rules	Placing, changing and deleting of flexibility bids only during trading period	high

4. Discussion

In the following section, we discuss how the targets presented in Section 2.4 can be matched with the proposed product design of capacity-based long-term flexibility products. We show that some of the product parameters can be interpreted as key design elements. In addition, we identify research needs for future investigations and for the implementation of LFMs.

4.1. System efficiency and gaming prevention

The primary prerequisite for the systematic implementation of LFMs is improvement to the efficiency of network operators' congestion management. Therefore, the usage of the procured flexibility must cause lower system costs than all alternative measures. This prerequisite implies three aspects: the prevention of strategic behavior, an optimized procurement and winner determination and the minimization of negative impacts on existing markets.

First, strategic behavior that can aggravate congestion – especially INC-DEC – must be prevented. The chosen capacity-based, long-term product design, in particular the hybrid remuneration that contains a competitive capacity payment in combination with regulated energy payments, is a suitable approach for the mitigation of INC-DEC. As the strike price follows the spot price signal, it does not contain an opportunity for strategic behavior (compare to Section 2.1):

- In "high generation/low load" network areas, flexible consumers are requested to increase the load and must pay for the energy with the current (zonal) spot market price.[16]
- In "low generation/high load" network areas, flexible consumers are requested to reduce the load and are paid for the energy with the current (zonal) spot market price.
- In both situations the flexibility provision is compensated with the capacity payment.
- The selection of requested flexibility assets follows a purely technical valuation as all assets' energy payments are equal.

In consequence, the INC-DEC strategy is not applicable as there is no incentive to artificially increase the short-term demand for flexibility. The premium of the capacity-based, long-term flexibility product must contain the compensation for all flexibility suppliers' costs. Therefore, the flexibility usage for congestion management can be interpreted as a regulatory approach.[17]

Second, the procurement and usage of required flexibility must be selected by the techno-economic optimization of cost considering the flexibility demand of all network operators. The techno-economic valuation combines specific cost and technical effectiveness in relation to the congestion. The technical core product must be the adjustment of electrical power (positive or negative) in a defined location within the network to enable the coordination of all affected network operators. Nevertheless, the efficiency of flexibility procurement can only be validated ex post, as the time slices of one week generally contain different congestion situations.

The main challenge for network operators – and consequently for the system's efficiency – is determining a suitable capacity volume for flexibility purchased in advance. Perfect efficiency would require a perfect congestion forecast for the relevant time slice. A higher procurement of flexibility

[16] For Germany, we suggest the "ID1" price of the intraday market.

[17] The market-based procured flexibility complements the regulatory cost-based flexibility usage.

results in unneeded capacity costs.[18] If the procurement of flexibility is too low, it is necessary to use alternative measures, such as the regulatory fallback option, that may be more costly.[19] Therefore, a suitable procurement strategy that is based on reliable forecast models and empirical data must be developed. In this context, the possibility of network operator coordination is also of outstanding importance. The formulation of the winner determination problem for the flexibility auction must consider the coordinated demand and technical dependencies to determine the techno-economic optimum required for the system's overall efficiency. Both procurement strategy and winner determination under consideration of network operators' coordination must be considered in further research.

Finally, the advantages of the LFM must not be overtaken by negative implications to other markets, such as a loss of market efficiency due to a reduced liquidity or a distortion of prices on the spot markets due to INC-DEC (Hirth and Schlecht, 2020; Hirth et al., 2019). Investigation into such effects and the implementation of suitable monitoring systems should also be a focus of future research.

Key elements in connection with system efficiency and gaming prevention are the technical core product with local component, the product time slice, the incremental time of use, the point of flexibility request, the remuneration in combination with pricing rules and the winner-determination.

4.2. Consideration of short-term preferences

The spectrum of individual participants' preferences is very complex and contains different conflicting interests. The two product aspects that are most related to the short-term preferences are the temporal dimension of the product and the technical rules.

As discussed in Section 3.2.2, the temporal organization of the flexibility product contains the trade-off between short-term planning and middle- to long-term risk management. The chosen time slice of one week balances both aspects as it represents a typical planning horizon for different participants. One important aspect in this connection is the availability of forecasts (e.g., for the weather but also for production capabilities and other individual restrictions). The second temporal parameter is the incremental period of use. The chosen increment of one quarter hour, which is in line with current spot market products in the EU, ensures the efficiency of the overall congestion management processes as it allows the network operators to switch between different congestion management measures. The same can be argued for the point of flexibility request, which should also be in line with existing processes. Nevertheless, different time horizons between the point of flexibility requests and the start of flexibility delivery are possible. From the suppliers' perspective, a preferably long time span between these points is advantageous for planning aspects. The remaining temporal parameter should enable an efficient flexibility trading without strongly affecting the participants' preferences.

The second major trade-off exists between reliability and the adaptability of available flexibility (see 3.2.3). In line with the overall system's efficiency, we argue that the reliability of the flexibility availability should preferably be on a high level to support individual network operators planning. Still, a secure maintenance of flexibility over one week can be challenging due to uncertainties related to individual behavior and other technical influences. Therefore, it is necessary to define

[18] IIn the worst case, the maintenance of flexible capacity may lead to weak liquidity of flexibility in other markets.

[19] The adjustment of the national regulatory framework for network operation is also an important aspect, especially to incentivize neither over- nor under-procurement. However, further developments of the regulatory framework are beyond the scope of this paper.

exceptions for the ensured availability that do not significantly decrease the overall reliability. We propose the definition of maximum requests per day, minimum time between requests and the restricted possibility to veto individual requests. The combination of high level of reliability and the definition of exceptions provides a compromise in the trade-off of technical rules. Well-defined rules and a monitoring system that prevents misuse are mandatory. Still, additional restrictions for individual technologies could be considered. Another major challenge is the translation of individual preferences related to small-scale assets into a pooled flexibility bid offered by a third-party aggregator. The consideration of different technologies and participant groups could lead to the specification of different product variants. If this is the case, the trade-off between individualization and standardization must also be considered. Therefore, the specification of technical rules is generally one of the most challenging tasks of flexibility product design.

Key elements related to short-term preferences are the incremental time of use, the point of flexibility request and technical requirements as well as restrictions.

4.3. Supporting long-term decision making

As discussed above, the temporal aspect of product design must generally consider short-term planning as well as middle- to long-term risk management. The latter also includes decisions related to the trade-off between network expansion and flexibility use as well as the supply-side decision of providing flexibility by exploiting existing unused flexibility or investing in new flexible assets. The proposed product design does not aim to refinance individual invests; instead, its aim is to dispatch existing flexibility in the most system-beneficial manner. The suggested planning horizon of one week is more concerted to short-term planning aspects than to middle- to long-term decisions. Still, a one-week product provides much more planning security than speculation on individual quarter hours during the concerned week. Therefore, the provision of flexibility in an LFM with the proposed product design can support a flexibility provider's business case.

From the network operators' perspective, the decision to expand a network depends on various aspects, first and foremost regulatory requirements that are beyond the scope of this paper. The opportunity of procuring network-supportive flexibility can influence this decision but must be based on a valid long-term evaluation. The relatively small time slices may contain advantages for the ex-post evaluation of flexibility procurement as they provide insights into the structure of flexibility provision over one year.

In conclusion, we argue that the chosen time horizons contain a compromise between short- and long-term planning that is suitable for LFM implementation. Based on information gathered once an LFM is implemented, the temporal aspects of the product and trading can be adjusted in connection with an iterative evaluation of the LFM design. Therefore, the key element for long-term decision making is the design of product time slices.

4.4. Outlook and further research

The discussion of the three targets reveals that the proposed product design does not support each of the targets equally. Still, we argue that the overall efficiency is the necessary prerequisite for a functional LFM, followed by the consideration of short-term preferences in order to achieve a liquid market. Further research is necessary regarding different topics. The realization of overall efficiency strongly depends on an integrated network operators' coordination scheme. The short-term coordination of congestion management measures must be complemented by mid-term coordination of flexibility capacity procurement. The details of the temporal framework and technical rules are strongly connected to short-term preferences. Finally, the temporal dimension of the product is also the basis for middle- and long-term planning aspects. Table 2 summarizes the key elements of product design for each of the three targets considering the implications for further research.

Table 2: Matching between targets and key elements

Target	**Relevant key elements**	**Further research implications**
Electricity system's efficiency must be ensured.	- Technical core product with local component, - product time slice, - incremental time of use, - point of flexibility request, - remuneration and pricing rules, - winner-determination.	- Definition of a suitable flexibility procurement strategy and winner determination under consideration of network operators' coordination. - Monitoring impacts on other markets. - Evaluation of necessary adjustments of the regulatory framework
Short-term preferences of network operators as well as potential flexibility suppliers must be considered.	- Incremental time of use, - point of flexibility request, - technical requirements, - technical restrictions.	- Evaluation of the chosen temporal product framework, - Definition of product variants suitable for different flexibility suppliers considering the trade-off between individualization and standardization, - Empirical investigation of the trade-off between reliability and adaptability.
Long-term decision making should be supported.	- Product time slice	- Evaluation of the chosen temporal product framework - Evaluation of necessary adjustments of the regulatory framework

The proposed product design can principally be adapted in each of the product parameters apart from the technical core product that must contain a local component. In particular, the development of a coordinated procurement strategy and the wide fields of temporal aspects as well as technical rules must be explored in more detail. In addition, some parameters may be suitable for an iterative improvement to the product design. Selected examples for such optional adaptions are as follows:

- The adaption of the activation condition from an exact technical value of electric power to a limited value of electricity consumption or generation. Such quota products reduce barriers to the flexibility providers as the risk of forecasting the availability of flexibility is transferred to the network operators. it can be argued that network operators can access the best possible data base to develop such forecasts.

- The organization of auction and the winner determination are strongly connected to the processes of network operators' coordination and may have to be adjusted regularly.

5. Conclusion and policy implications

The present paper contributes to the discussion of LFMs as one possible extension for future congestion management. We focus on the network-supportive use of DR as there is an unused flexibility potential that can complement the existing measures of supply-side flexibility to reduce costs in the overall system as well as costs for individual network operators. We argue that DR's flexibility can only be utilized with a market-based approach as the individual costs of this flexibility are generally unknown and depend on various influencing factors such as technical conditions and individual preferences. Therefore, here we have provided and discussed a proposal for an LFM's product design that is suitable for the efficient utilization of DR. Our methods include four steps.

In the first step, we provided an overview of the theoretical background and reviewed the challenges, requirements and barriers that exist in the context of LFM from both sides of the market. As an interim conclusion, we have presented three overarching targets. The first target is ensuring the overall system's efficiency. This aspect entails decreasing system costs and therefore implicitly the prevention of undesired strategic behavior, especially INC-DEC. The second target considers the short-term preferences of network operators as well as flexibility suppliers. The third target is the support of long-term decision making for both sides of the market.

The second step was to propose a capacity-based, long-term flexibility product. In terms of energy trading, such a product design is generally known as call option. This call option should cover time slices of one week and consider the individual preferences of network operators and flexibility providers as technical rules and restrictions. The premium for the flexibility capacity provision is determined by an LFM auction. The strike price is regulated and based on the intraday trading result. We used an existing framework by Heilmann et al. (2020) with small adjustments to present a structured overview of a detailed product design highlighting the most relevant parameters.

In the third step we discussed how the presented product proposal meets the three overarching targets of the theoretical background. One major advantage of the chosen design is the prevention of INC-DEC as there is no more short-term opportunity between the LFM and the energy spot market. The major challenge to improving the overall efficiency of congestion management is the definition of a suitable procurement strategy and winner determination when considering network operators' coordination. The short-term preferences are mainly addressed by the definition of technical rules. Still, two major trade-offs for technical rules exist, namely standardization versus individualization and reliability versus short-term adaptability. Another trade-off occurs for the temporal dimension, as the chosen one-week time horizon is suitable for various short- to mid-term planning aspects but does not provide a valid basis for investment planning.

In the fourth step, we suggest the following policy implications, addressing decision makers in the European energy economy, in particular network operators:

- The implementation of LFMs to complement existing regulatory congestion management measures is a promising approach for the utilization of DR for future congestion management.

The prerequisite for an extensive implementation of LFM in Europe is an improvement to the overall efficiency of congestion management processes.

- The implementation and the operation of an LFM must be supported by a sophisticated monitoring concept. The monitoring should provide insights into the occurrence of congestion, the procured flexibility capacity and the used flexibility as basis for an assessment of the development of congestion management cost and impacts on other energy markets.

- We recommend the implementation of LFM with capacity-based, long-term flexibility products as such products are suitable for the mitigation of strategic behavior, in particular INC-DEC.

- Although the presented product proposal provides some major advantages, there is still significant space for adjustments and respecifications. Such adjustments must be prepared carefully as the different parameters affect each other. This is especially true for the identified key elements. Still, we recommend adapting the product design if it is technically or economically expedient.

- Finally, we emphasize areas for further research (see Table 2). First, the definition of a procurement strategy and winner determination considering network operators' coordination is mandatory for system-optimal congestion management. In addition, the product design must handle the trade-offs between individualization and standardization, reliability and adaptability and short-term planning and long-term decision making. For an iterative optimization of the flexibility product design, as suggested by Heilmann et al. (2020), a sophisticated monitoring system (see item ii) is also mandatory. Finally, the regulatory framework that is the basis for short-term efficiency as well as long-term investment decisions should be evaluated to ensure consistent rules and incentives for the implementation and usage of LFMs.

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