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Title: Local Flexibility Markets and Business Models

Year: 2023

Version: Accepted manuscript

Please cite the original version:

Zornow, F., Talari, S., Ketter, W., Ebrahimi, M. & Shafie-khah, M. (2023). Local Flexibility Markets and Business Models. In: Shafie-khah, M. & Gazafroudi, A. S. (eds.) *Trading in Local Energy Markets and Energy Communities: Concepts, Structures and Technologies*. Lecture Notes in Energy, vol 93. Cham: Springer. https://doi.org/10.1007/978-3-031-21402-8_7

Local flexibility markets and business models

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Abstract

Current energy systems are experiencing a transformation led by incentives to reduce greenhouse gas emissions and increase the share of renewable energy sources (RES). This way, the integration of RES into energy systems is one of core issues. However, only depending on grid investments to deal with increasing loads and integration of RES is not the way to tackle this issue, because it would be too costly. Flexibility is defined as the change of energy generation or consumption patterns in response to a specific signal. This flexibility is then offered as a service to support actors in the energy system. Local flexibility markets are identified as platforms that coordinate and provide flexible assets. This chapter aims to provide an overview of local flexibility markets and their business models. This chapter analyzes the proposed local flexibility market designs in Europe, and discusses on their drawbacks and barriers, and how they can be improved.

Keywords: Electricity market, Local flexibility market, Business models, barriers, market design.

1 Introduction

1.1 Motivation and aims

Current energy systems are experiencing a transformation led by incentives to reduce greenhouse gas emissions and increase the share of renewable energy sources (RES). This way, the integration of RES into energy systems is one of core issues. However, only depending on grid investments to deal with increasing loads and integration of RES is not the way to tackle this issue, because it would be too costly (Schittekatte et al., 2020, p.1; Minniti et al., 2018, p.1).

First and foremost, flexibility is defined as the change of energy generation or consumption patterns in response to a specific signal. This flexibility is then offered as a service to support actors in the energy system. It appears that both supply and demand sources can be used as flexibility sources (Ebrahimi et al, 2022, p. 1). In this regard, upward-regulation means more generation or less consumption, and downward-regulation means less generation or more consumption, accordingly (Sánchez-Jiménez et al., 2015, p. 12).

Local flexibility markets (LFMs) are identified as platforms that coordinate and provide flexible assets. This flexibility can then be offered to the Distribution System Operator (DSO) for managing the distribution system in an efficient way preventing possible problems such as congestion. (Zeiselmair et al., 2021, p.1). There are already flexibility markets in Europe that aim to make distribution grids more efficient and decrease grid investments. Establishing a local flexibility market would offer flexibility products provided by DER and flexible demands. It also provides an access to a market platform for DER. Influential unions of DSOs and Transmission System Operators (TSO) pointed out the urgency for flexibility provision in Europe. It was also demonstrated how TSO-DSO coordination could allow both operators to access different flexibility products that assit them address system operations challenges such as congestion (Valarezo et al., 2021, p.1).

Nevertheless, the role of the consumer becomes more critical owing to self-generation and improved information and communications technology (ICT) technology that allows better tracking and control of loads, resulting in a decreased electricity bill for the consumer (Olivella-Rosell et al., 2018, p. 4). Due to a lack of a real-world applicable business model for local flexibility markets, the relevance of this topic is emphasized.

This chapter aims to provide an overview of Local flexibility markets and their business models. Consequently, the following research question is to be answered: “What are the proposed business models for LFM, what are their drawbacks and barriers, and how can they be improved?”

1.2 Literature review

Articles, documentation, and websites were categorized based on a concept matrix presented by (Webster & Watson, 2002, p. 17). Since this work’s focus is to provide an overview of existing business models, their drawbacks and barriers, and possible improvements, the categorization of the concept matrix will have an upper category “local flexibility markets” with sub-categories “Business models”, “Drawbacks and Barriers” and “Improvements”. The sub-categories will be divided into smaller sections to provide a wide-ranging solution to the research questions.

Table 1 Concept Matrix

	Local flexibility markets																			
	Business models											Drawbacks and barriers			Improvements					
References	Enera	GOPACS	Picloflex	Nodes	EcoGrid 2.0	Tiko	Equigy	Interflex	Parity hybrid model	CoordiNet	FLEXIMAR	Drawbacks of LFMs	Barriers to adoption	Inc-dec gaming	Countries’ different needs for flexibility	LFM design with network constraints	Fair and efficient flexibility markets	Fairness vs. Welfare	Enera hybrid model	Nodal vs. zonal pricing
[1]										✓										
[3]		✓													✓					
[4]								✓				✓								
[5]																				✓
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The rest of the chapter is organized as follows. In the next section, various proposed business models for LFMs are analyzed. The third section presents the drawbacks and barriers to LFMs. The fourth section suggests how LFMs can be improved or what alternatives there are. The fifth section discusses this work's results and evaluates whether the objective and research question are answered. The last section concludes the chapter and gives an outlook for further future research.

2 Proposed Business Models

This section analyzes the proposed local flexibility market designs in Europe thoroughly. Due to the absence of publicly available documentation of specific projects, some projects are explored in more detail than others.

2.1 Enera

Enera is a German project coordinated by EPEX spot, EWE AG, and local TSOs and DSOs (namely Tennet DE (TSO), Avacon Netz (DSO), EWE Netz (DSO)). It aims to coordinate the supply and demand of flexibility, help the DSOs in congestion management and minimizing the curtailment of renewable energy generation.

Furthermore, the platform offers network operators a local order book, where network operators can buy flexibility to solve congestion issues. A demonstration of a local order book can be seen in Figure 1 (Schittekatte et al., 2020, p. 4).

Local Market X	Bid		Ask	
Product	Qty	Price	Qty	Price
DE 9:00 Local X	11	41	4	39
DE 9:00 Local X	8	35	11	40
DE 9:00 Local X	3	32	7	33
DE 9:00 Local X	5	27	3	29

Figure 1 Local Order Book

The main functions of the project include the collection of bids, market clearing, monitoring, settlement, introducing aggregation activities, network impact computations, and flexibility activation (Valarezo et al. 2021, p. 4).

The given market is a two-sided market, where TSOs and DSOs are buyers of flexibility and aggregators, and asset owners are sellers of flexibility. Moreover, the market is synchronized with the intraday market of EPEX Spot, which means the clearing period is like the intraday market (15 minutes), and the delivery period is 15 or 60 minutes. The trading happens on a different platform, even though the platform's access uses the identical API as trading on the EPEX Spot exchange. The pricing method is pay-as-bid. Bidding is a continuous process, and received bids are matched on the platform. Settlement is executed as dispatch payments, and participants are billed at the end of each month for their collected trades. The offered flexibility is devotions to change the load or production of a particular participant. When activating that flexibility, the participant’s portfolio is affected by the provision of flexibility. The participant then must ensure that its portfolio is still balanced, which can be done on the intraday market. Additionally, research funds are used to continue the platform. It is to be noted that Enera is merely a pilot project (Valarezo et al. 2021, p. 11).

Regarding TSO-DSO coordination, both network operators are anticipated to exchange information bilaterally when buying flexibility to avoid conflicting activation. However, going forward, the idea is to create a mechanism that filters offers so that no such complications in activation can occur (Schittekatte et al., 2020, p. 8).

The project's main achievements include the development of the flex registry, which is a registry with all flexible assets and their characteristics. Moreover, a verification platform was developed that verifies the flexibility delivery. Lastly, a framework that controls the processes and interactions on the platform was presented (Sommer et al., 2020, pp. 3-5).

The project participation was voluntary, and the network operators did a prequalification to evaluate the usefulness of new aspiring participants. Additionally, there were no penalties for the non-delivery of flexibility products, which makes sense in hopes of lowering the entry barriers for new participants. Nevertheless, it would be reasonable to implement penalties in more mature flexibility markets (Schittekatte et al., 2020, p. 8-9).

Moreover, it is worth noting that since October 2021, a new regulation for redispatch called Redispatch 2.0 has come into effect. This regulation allows grid operators to control renewable energy plants and CHP plants that have a capacity of 100 kW and above. These smaller assets are then included in the redispatch process. Nevertheless, the new redispatch regulation only considers generation and storage units. This regulatory framework completely ignores demand-side flexibility. To tackle this issue, a hybrid model was proposed to consider non-regulated assets. More about this is in section 5.5 (Sommer et al., 2020, p. 6).

2.2 GOPACS

GOPACS is a Dutch platform owned by the Dutch TSO and DSOs and launched in 2019 that is currently in operation. GOPACS is not a market, yet it is connected to Dutch's national energy market platform, the ETPA. Moreover, GOPACS is in contact with other market platforms (Epex Spot, Nord Pool), with ambitions to connect these platforms to GOPACS. (Valarezo et al., 2021, p. 5; [10])

The platform deals with congestions at all voltage levels, offering flexibility for redispatch and TSO/DSO coordination. Moreover, grid operators forecast and report congestion management needs using the platform. Trading is not executed on a different platform because it is integrated into the existing market structure. Flexibility is offered on the ETPA as a subgroup of the wholesale order book, and flexibility providers must include locational information for the offer. As the trading is executed on the ETPA, the market is two-sided. DSOs and TSOs are buyers of flexibility, and sellers of flexibility can be residential, industrial, and energy companies. The market is continuous, and the market platform carries out the settlement. The market operator is reimbursed by the flexible service providers in the form of an entry fee, a monthly fee, and a fee for every delivered MWh. Additionally, grid operators are required to pay a fee for using flexibility products. Flexibility products on GOPACS are unique. Therefore, for every purchase order, a sell order is matched even if the sell order has a higher price than the buy order. The network operator pays the difference between the orders to assure the execution. This type of product is called IDCONS (Intraday Congestion Spread). However, the bids are only matched if they are located sufficiently in the network, so the process is still cost-efficient. A procedure for this type of product can be seen in Figure 2 (Valarezo et al., 2021, p. 11; Schittekatte et al., 2020, pp. 4-6; Dronne et al. 2020, p. 5).

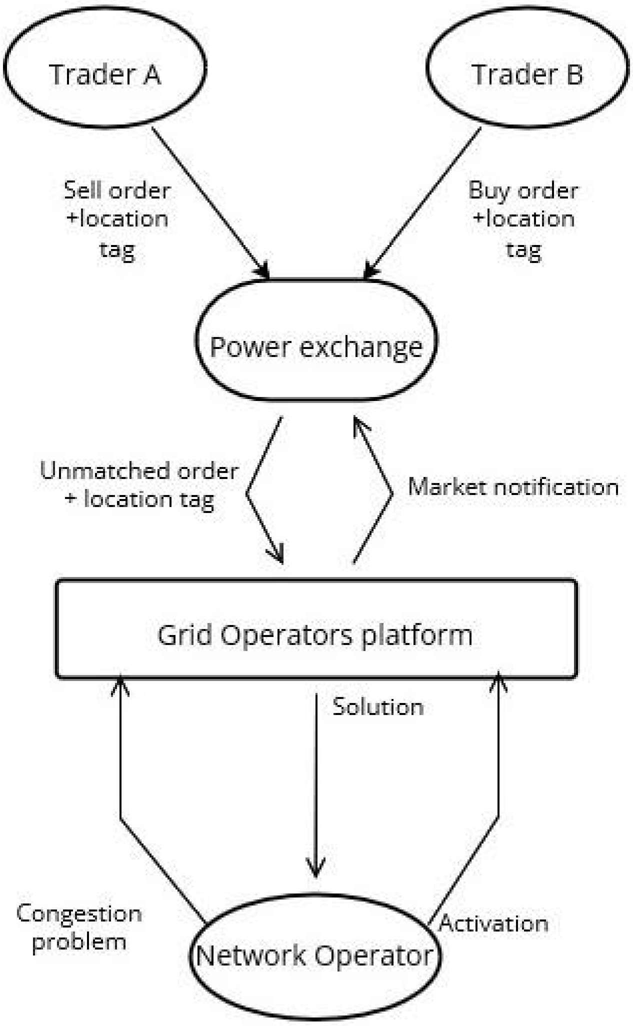

Figure 2 IDCONS Product

2.3 Picloflex

Picloflex is a marketplace based in the UK and has been operating since 2019. The key objectives of Picloflex are developing a marketplace to offer standardized flexibility products to DSOs, reduce grid reinforcement costs, and operate the system in a more efficient way. DSOs are provided with a platform where they can declare their flexibility needs based on locational information. On this platform, DSOs monitor available assets for use in the constrained zone and obtain flexibility suited for their requirements. Interestingly, the platform only offers services to DSOs and not TSOs. Aggregators, asset owners, consumers, communities, electric vehicles, and generators can offer flexibility. The provided platform is not integrated with existing energy markets (Radecke et al., 2019, p. 8; Schittekatte et al., 2020, pp. 4-6).

Picloflex differs from other marketplaces, since it is auction-based, and flexibility is offered with a lead time of six months to 4 years. A flexibility provider must submit prices for availability,activation, and a maximum running time. Therefore, flexible service providers are compensated for dispatch. It is also to be noted that making reservation payments and contracts with multiple services is possible in this marketplace (Valarezo et al., 2021, p. 11).

2.4 Nodes

Nodes is an international business case that aims to improve grid operation by procuring flexibility for network operators and therefore enhance congestion management options. It has been in operation since 2018 and is owned by the European Power exchange Nord Pool. Nodes has a variety of use cases across different countries, including Germany, Norway, Sweden, and the UK. In the German case (the Mitnetz case), Nodes established a project with a German DSO to test if a market-based solution could enable better local flexibility utilization for reducing congestion due to an oversupply of energy. This project aimed to reduce the curtailment of renewable energy generation. As a result, curtailment costs paid to renewable energy providers were significantly reduced, and 240 tons of carbon emissions were saved (Sarti, 2020, p. 8; Valarezo et al., 2021, p. 5)

In addition, other projects like Norflex in Norway, Intraflex in the UK, and Sthlmflex in Sweden were established by Nodes. There are also incentives to create a universal approach to provide flexibility for DSOs and their interaction with flexibility markets. The project EUniversal pursues this aim in Germany, Poland, and Portugal (Sarti, 2020, p. 10-11).

Nodes offers flexibility products for DSOs, TSOs, and Balancing Responsible Parties (BRP). The platform is integrated into existing energy markets so that the trading is executed on the intraday timeframe. Additional flexibility that is not required by network operators or BRPs is forwarded to other energy markets. A visual representation can be seen in Figure 3.

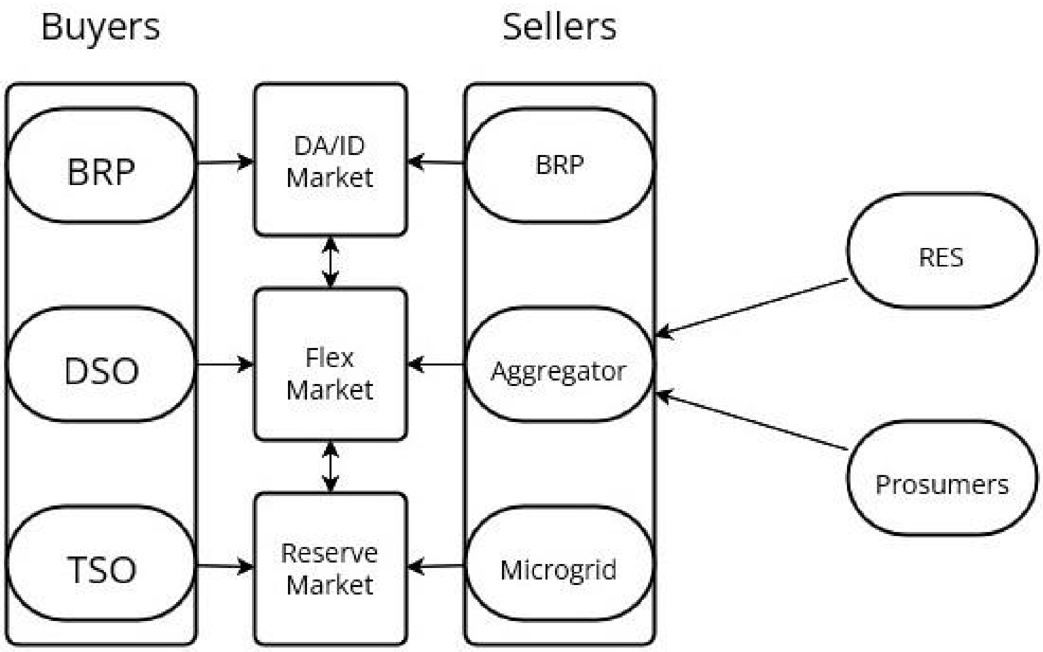

Figure 3 Nodes Market Design

The Nodes market is unique as it offers the purchase of so-called LongFlex, which enables DSOs to make availability payments to secure the possibility of receiving flexibility over a defined period. In addition, it offers the ShortFlex market, where flexibility can be acquired to solve network congestion. Furthermore, the flexibility service providers and asset owners can submit their assets to the platform, where they compete with other flexibility service providers, and thus create an order book. Flexibility products on Nodes are not standardized, as flexibility providers can modify specific parameters like order, time, and location (Schittekatte et al., 2020, pp. 6-7; Sarti, 2020, p. 7-12).

2.5 EcoGrid 2.0

EcoGrid 2.0 is a local flexibility market-based in Denmark that shows how households can offer flexibility services to DSOs and TSO through demand response. The project is located on the island Bornholm, and approximately 800 households participate. Every household owns a smart meter, a communication and control device, and an electric heating unit. Aggregators play a significant role in this project by controlling and optimizing an aggregation of DERs; they can operate in the wholesale market. An overview of the EcoGrid setup can be seen in Figure 4 (Heinrich et al., 2020, pp. 6-7).

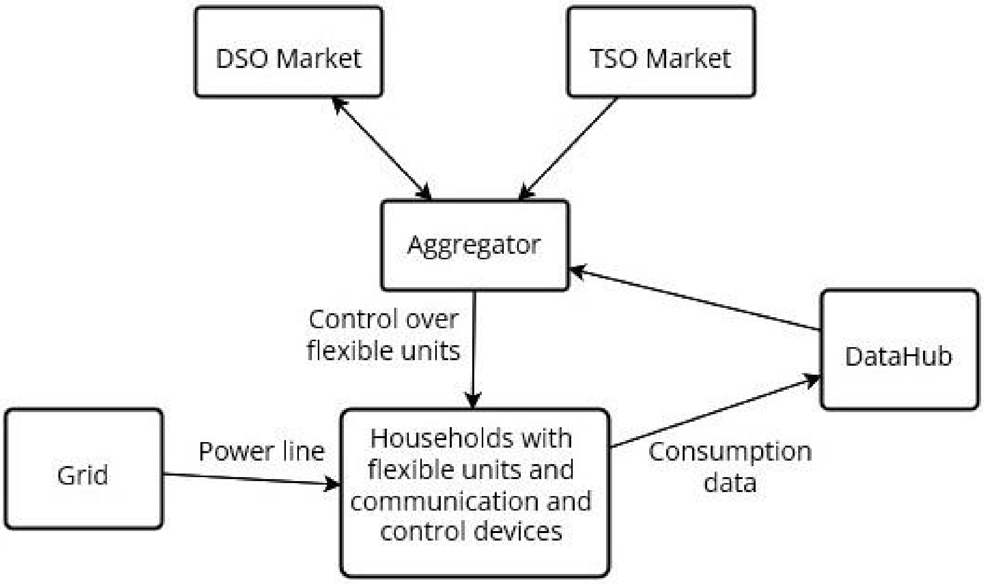

Figure 4 Ecogrid Setup

The DSO and aggregators must access the smart meter data from participants. DSOs need participants data for calculating their flexibility needs and aggregators need the data to control DERs and determine the amount of flexibility they can provide. DSOs use aggregated data, and consumers in Denmark are energy aware, thus willing to share data, making it more unlikely that data privacy concerns will arise (Heinrich et al., 2020, p. 7).

The EcoGrid 2.0 introduces two flexibility services for the DSO, the capacity limitation service and the baseline flexibility service. These services can be scheduled or conditional. Scheduled services are activated during a predetermined and regular point of time, while conditional services must be activated manually by the DSO (Heinrich et al., 2020, p. 8).

The capacity limitation service limits the power consumption of an aggregator, so his portfolio cannot exceed the consumption limit for a specific period. An example of this service can be seen in Figure 5 (Heinrich et al., 2020, pp. 8-9).

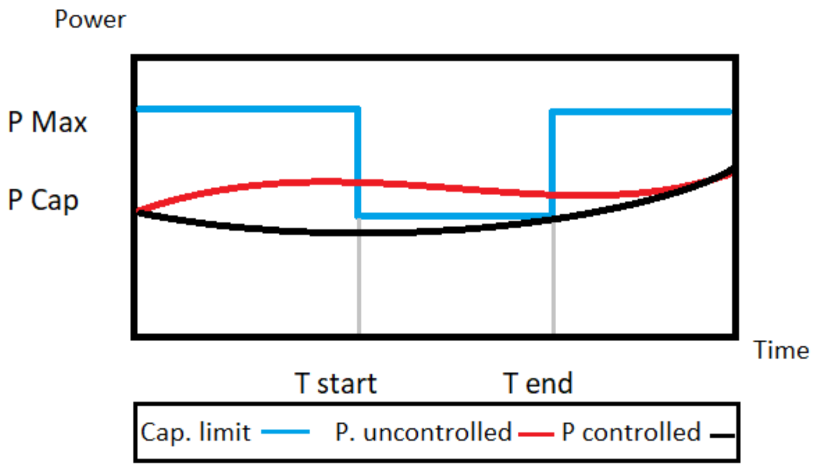

Figure 5 Capacity Limitation Service

The baseline flexibility service is distinguished by the baseline, an estimated power consumption if the aggregator did not interfere in delivering the service. In this service, the aggregator must first change the load into one direction. Then after a specified period, he changes the load into the opposite direction for the same period. An example of this service can be seen in Figure 6 (Heinrich et al., 2020, pp. 9-10).

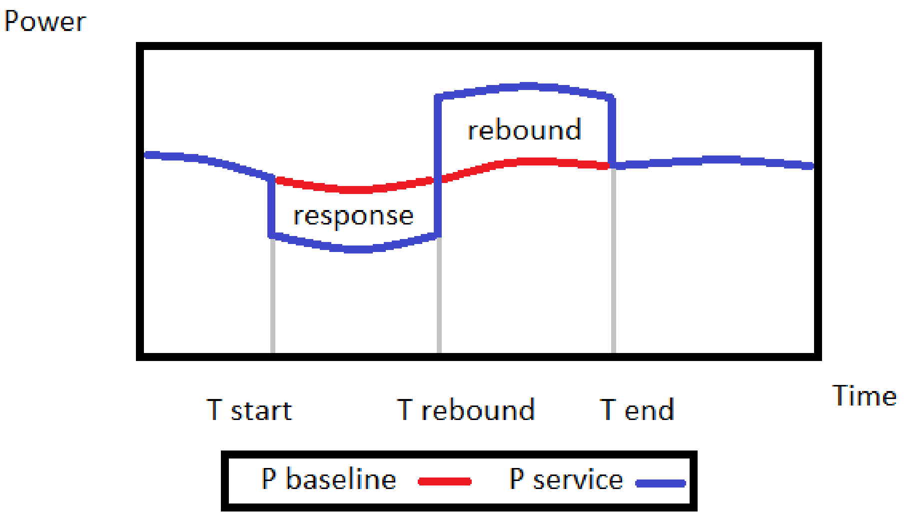

Figure 6 Baseline Flexibility Service

The procedure of how flexibility is acquired starts with the DSO. Firstly, the DSO models the load in the network to assess the time of possible congestion.

Secondly, the DSO begins an auction by providing the market operator with several service requests that might be needed. The auction must be done within a lead time of one to twelve months. The auction information is then forwarded to aggregators (without the price indicated by the DSO), who then calculates the service cost and send back a list of services they want to provide. Ultimately, the most economically beneficial service is chosen, and a standardized contract is made between DSO and aggregator. There also is the possibility that the offered service is conditional. In that case, the DSO must evaluate whether to activate the service or not. The DSO only activates the service if the activation cost is lower than the expected benefit (Heinrich et al., 2020, pp. 10-11).

2.6 Tiko

Tiko is an aggregator platform in Switzerland launched in 2014 and is still in operation today. The main goal of Tiko is to aggregate the behind-the-meter assets from Swiss households, like residential photovoltaic and electricity-based heating systems, to provide flexibility to the Swiss TSO. The flexibility the platform offers is primary and secondary balancing services for the Swiss TSO. Apart from the aggregator platform, Tiko also provides the technology used for this implementation in Germany, Belgium, France, and Austria. The platform only operates in low voltage DSO grids. The settlement for trades is firstly done on the TSO balancing market between the aggregator and the TSO, and secondly on Tiko's platform between the aggregator and the flexibility service providers. The TSO continuously acquires flexibility for the following week. Tiko generates its income from the services for the transmission grid and equipment sales, and subscriptions of customers (Valarezo et al., 2021, pp. 14-17)

The Tiko system consists of four parts: actors and sensors, gateway, Frontend, and Backend, in addition to some additional services.

- Actors and Sensors: The K-Box is a vital device for measuring and controlling. It controls and measures appliances like heat pumps, air conditioning, or EV charging stations. Measured data is forwarded to the Backend to determine the state of the device and the control decision variables. Moreover, the device is equipped with a relay that Tiko used to shift the consumption (Geidl et al., 2017, p. 6).

- Gateway: The earlier explained K-Box is connected to the M-box. The K-Box sends its data to the M-Box using the power line communication. The M-Box is an intermediate device that provides the Backend with data from the K-Box (Geidl et al., 2017, pp. 6-7).
- Backend: The primary function of the Backend is the algorithm that decides on control actions for the connected devices. Control decisions are made by analyzing various parameters. Customer comfort is guaranteed not to go beyond a specific limit. The typical behavior of the connected devices is examined using big data analysis (Geidl et al., 2017, p. 7).
- Frontend: The Frontend provides the customer with several functionalities. Firstly, the customer can visualize his historical consumption patterns via a web app or a smartphone app. Secondly, an Eco-mode allows the customer to reduce energy consumption significantly. In addition, the customer is alarmed in case energy consumption is unusual. Lastly, one can benchmark his energy consumption with other participants in the Tiko system (Geidl et al., 2017, p. 7).

Even more services are connected to the platform, including rollout and installation planning tools, a customer support portal, and an ERP system (Geidl et al., 2017, p. 8).

2.7 Equigy

Equigy is a blockchain-based initiative of European TSOs that intends to actively enable households to participate in the energy transition and generate flexibility from decentralized systems. The crowd balancing platform has projects in Germany, Italy, Switzerland, and the Netherlands. The platform allows aggregators to provide flexibility for grid balancing purposes through various consumer-based appliances, like batteries and heat pumps. Blockchain technology is responsible for validating and executing the transactions and validating the provision of flexibility services. The flexibility services the platform offers vary depending on the country of application. For instance, in the Netherlands, aFRR services, in Switzerland, FCR and RR services, in Italy, RR services, and in Germany, Redispatch services are offered.

In addition to that, the platform also provides congestion management services for DSOs. The crowd balancing market is integrated into ancillary service markets from Germany, Switzerland, Italy, and the Netherlands. However, the platform can coexist with these existing markets if something fails. It is to be noted that the platform is not profitable. (Fabel et al., 2021, p. 6; Valarezo et al., 2021, p. 14-17; Niet et al., 2021, p. 7-12;[6])

2.8 Interflex

Interflex was a project with demonstrations in Germany, France, Sweden, Netherlands, and the Czech Republic from 2017-2019. The demonstrations focus on how the DSOs can use flexibility to solve their challenges on the distribution grid. In these demonstrations, flexibility is exclusively offered to the DSO and not to the TSO. Two kinds of approaches were used to provide. In the first approach, there were no external participants like aggregators. DSOs directly manage residential assets to activate flexibility. The German and Swedish demonstrations made use of this kind of approach. The second approach incorporates aggregators into the market setup. A market setup for the Dutch demonstration can be seen in Figure 7 (Valarezo et al., 2021, p. 7; Pourasghar et al., p.3).

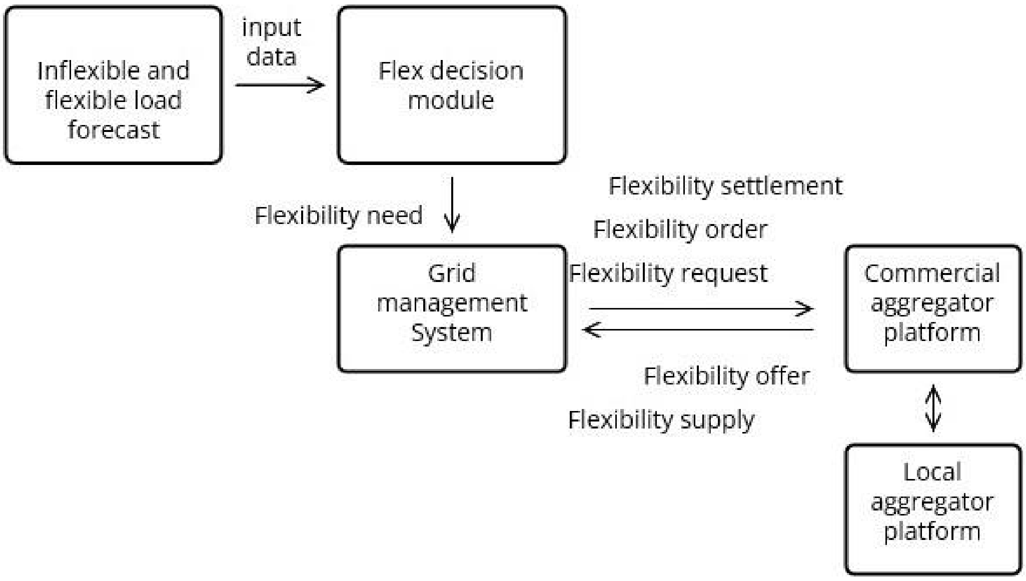

Figure 7. Dutch Interflex Market Setup

In Interflex, there are three mechanisms for the DSO to activate flexibility.

- In the first mechanism, the DSO owns and directly controls flexibility assets. Batteries are mainly used to offer flexibility. In the French demonstration, the DSO directly controls a battery to solve grid congestion. In the Swedish demonstration, a central battery and a backup generator are used to make islanding possible(Dumbs et al., 2019, p. 3).
- The second mechanism depends on legal and contractual obligations, which define the use of flexibility. For example, in the German demonstration, flexibility providers are obliged to respond to DSOs signals in case of grid congestion. The flexibility in that demonstration is usually the temporal curtailment of solar energy. The DSO in Sweden has a contract with the customer to control flexibility units like heat pumps and batteries by sending signals from the system . (Dumbs et al., 2019, p. 4).
- The market response mechanism is the third mechanism to activate flexibility for the DSO. In this mechanism, the flexibility provider responds to the DSOs market demands in the form of flexibility bids activated when specific rules are satisfied. The aggregators in the French and Dutch demonstrations receive DSOs requests on their respective market platforms. Contracts with their customers allow them to control their assets using the platform. A process for the French demonstration can be seen in Figure 8 (Dumbs et al., 2019, p. 4).

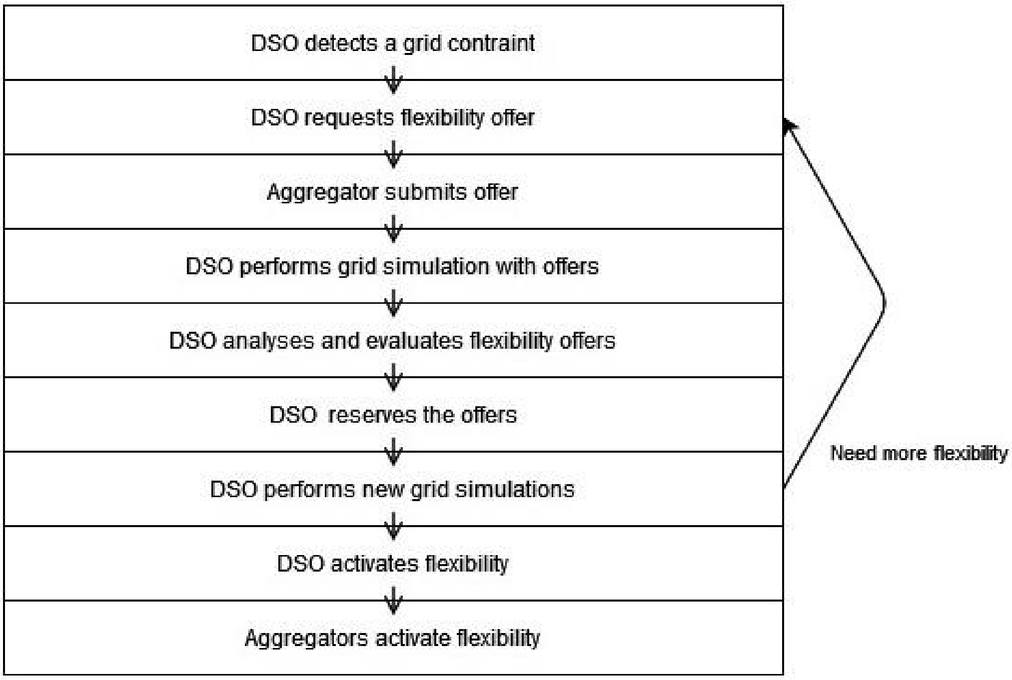

Figure 8. Market Process French Demonstration

2.9 Parity Hybrid Model

2.9.1 Platform Setup

Parity is a market framework that implements a Local Energy Market (LEM) and an LFM simultaneously. Three main goals are pursued with this proposal. On the one hand, flexibility should be offered to the DSO for congestion management and voltage control. On the other hand, prosumers should be integrated into the process of providing flexibility. Lastly, prosumers should be able to trade locally produced energy among themselves. (Pressmair et al., 2021, p. 7)

The P2P energy trading takes place on a blockchain-based platform operated by the Local Energy Market Operator (LEMO). However, a LEM does not solve congestion management issues. On the opposite, it could even contribute to these issues. That’s why there is an additional LFM implemented in this market. The LFM can be implemented either implicitly or explicitly. The implicit LFM does not require a separate market platform. The congestions in the grid are implicitly solved by the DSO giving off different prices for locations. The DSO forecasts where potential congestion might occur and changes the network tariff accordingly. The prosumers then must react to the price signals and adjust their consumption profile accordingly. If the prosumers respond by lowering their load at higher prices or increasing their load at lower prices, congestion can be avoided. This type of market requires the regulator to make variable grid tariffs possible. This type of market can be seen in Figure 9 (Pressmair et al., 2021, pp. 7-8).

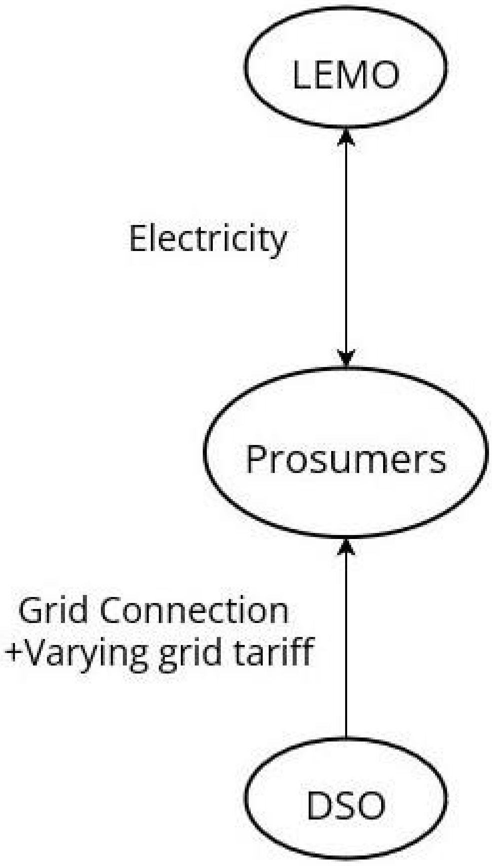

Figure 9 LEM with Implicit LFM

On the other hand, there is the explicit LFM. In this concept, the DSO buys flexibility on a different market platform. This market platform is operated by a separate entity called the Local Flexibility Market Operator, or LFMO. The flexibility for the DSO is always unconditional. This is because long-term availability payments would restrict the way the LEM operates. Prosumers of the LEM cannot assure the provision of flexibility over a longer time. The LEMO acts as an aggregator because it sells flexibility to the DSO using a BRP. After all, the LEMO is responsible for delivering the flexibility and charging the prosumer a varying fee on each trade in the LEM to achieve altered consumption patterns. A setup for the explicit LFM can be seen in Figure 10 (Pressmair et al., 2021, pp. 7-8).

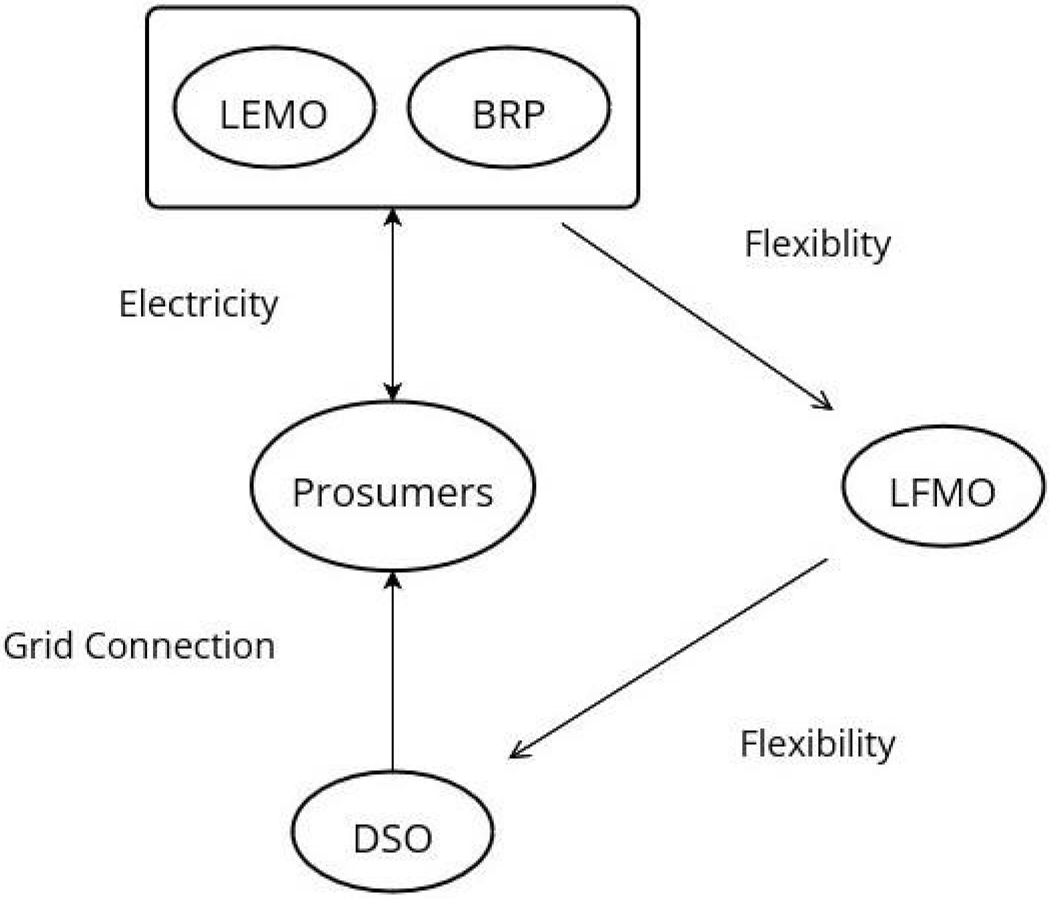

Figure 10 LEM with Explicit LFM

2.9.2 Wholesale Market Integration

The proposed model also allows the prosumer to provide ancillary services to the TSO. That is done by aggregators that acquire flexibility on the market platform. The market operator then turns the requested flexibility into prices for the prosumer. When the flexibility is activated, the market operator needs to change the price while considering price elasticity to change the consumption pattern of prosumers. Forecasting and automatic energy dispatch must be on point for a smooth operation. The market operator carries the risk of the uncertainties of delivering flexibility. Therefore, the aggregator's energy portfolio must be large and diversified to ensure safe operation in case of non-delivery (Pressmair et al., 2021, p. 10).

2.9.3 Coordination of Flexibility

There are three different types of grid operation. There is the green, yellow, and red operation state. The DSOs forecasts determine the grid state. The green state means that no constraints are forecasted. The prosumers automatically trade P2P energy. The DSO applies the usual grid tariff, and the aggregator and LEMO operate as usual. In the yellow state, the DSO forecasts some form of constraint. Here the DSO acquires flexibility from the LFM. The aggregator cannot buy flexibility in that state. However, the P2P trading among prosumers continues. The red state is only applied when the flexibility from the LFM does not solve the forecasted congestion. The DSO directly controls loads that jeopardize grid stability. In this case, the whole market platform halts. Moreover, P2P trading has also stopped.(Pressmair et al., 2021, p. 10).

2.10 CoordiNet

The CoordiNet is a European project with demonstrations in Greece, Spain, and Sweden. The demonstrations pursue different goals suited to their local needs (Madina et al., 2020, p. 1).

2.10.1 Greek Demo

In Greece, the goals are to engage consumers and RES to participate actively in power systems. Moreover, reducing the costs and increasing the quality of energy by presenting innovative products and services (Madina et al., 2020, pp. 1-2).

In Greece, a multi-level and fragmented market model is used to solve congestion and voltage issues. A multi-level market model means that the DSO and TSO have separate markets for their flexibility needs. The fragmented market model only allows flexibility assets to offer their flexibility to the system they are connected to. For example, a flexible asset connected to the transmission system can only offer services for the TSO. Likewise, a flexible asset connected to the distribution system can only offer services to the DSO(Madina et al., 2020, pp. 3-4).

The essential services for the network operators are congestion management and voltage control services. The services are traded on the Day-ahead and Intra-day market (Bachoumis et al., 2019, p. 23).

Primary use cases are load and RES forecasting on transmission and distribution grids, state estimation on both grids, market platform models, and a DSO/TSO coordination platform (Madina et al., 2020, p. 4).

2.10.2 Spanish Demo

Spain’s demonstration aims to provide evidence that Local Flexibility Markets integrate flexible assets of every size and location to support network operators by offering grid services (Madina et al., 2020, p. 1).

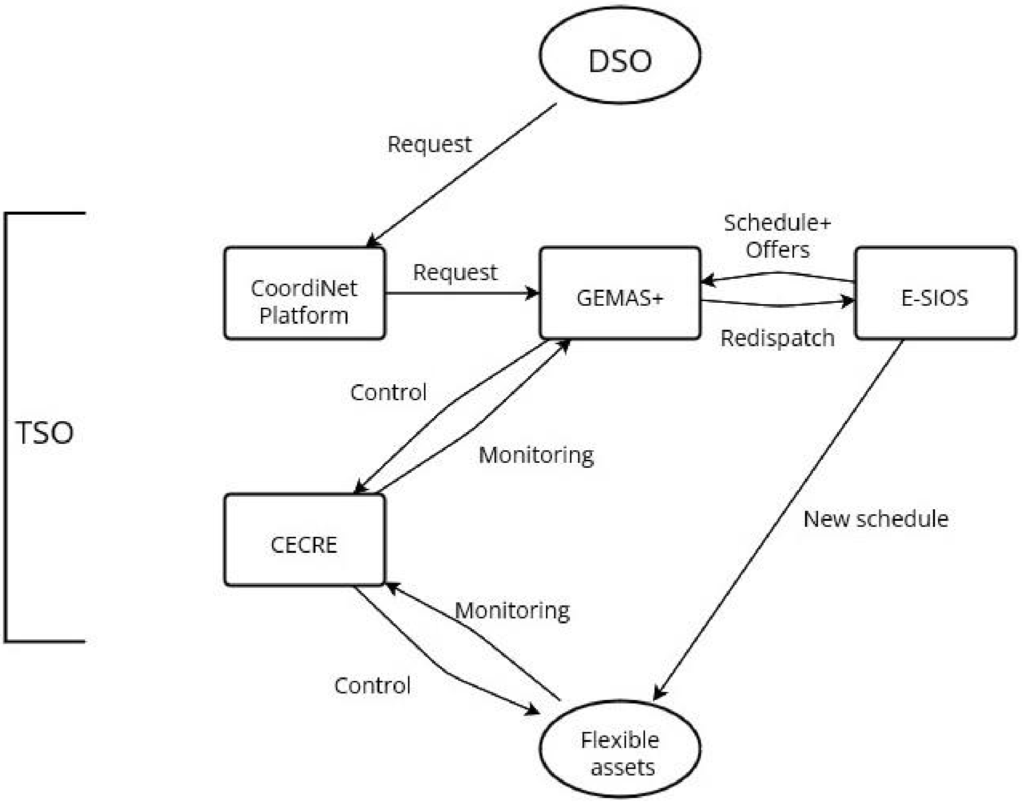

Figure 11 CoordiNet Spanish Setup

In Spain, congestion issues are solved using a local and a common market model. The local market model only considers flexibility for the DSO and disregards the central flexibility needed for the TSO. On the other hand, in the common market model, DSO and TSO can procure flexibility on a single market platform. A setup for the platform can be seen in Figure 11 (Madina et al., 2020, pp. 3-4).

The CECRE is the Control Centre of Renewable Energies. It is the connection point between the TSO and renewable generation. The GEMAS+ is responsible for evaluating the system's state. It also calculates the power reduction in case the system must return to a safe condition. E-SIOS manages the incoming bids for the balancing markets and assures the grid's economic and consistent operation. E-SIOS and GEMAS+ needed modification for the CoordiNet project to be successfully applied (Madina et al., 2020, p. 5).

2.10.3 Swedish Demo

The Swedish demonstration intends to electrify their society for a sustainable future. Therefore, it aims to achieve the national goals for renewables and climate. It is also expected that these markets support economic growth in that area. Additionally, a P2P trading mechanism is facilitated in the Swedish demo (Madina et al., 2020, p. 2).

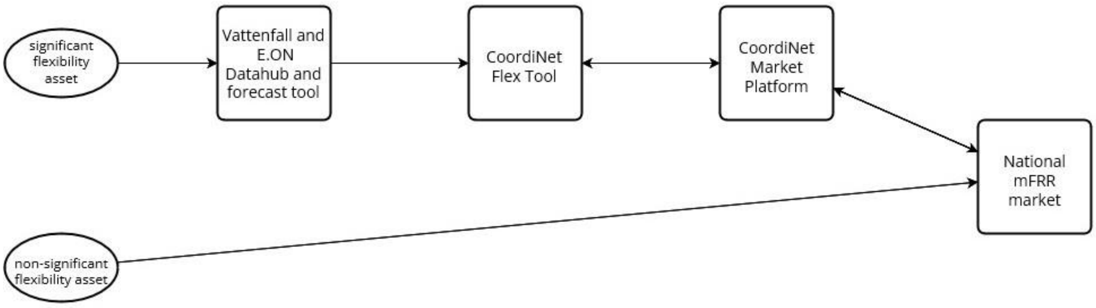

Figure 12 Swedish Setup

In Sweden, multi-level and distributed market models are used to manage congestion. The distributed market model solves flexibility needs using P2P trading. The DSO and TSO create incentives to align their objective with the participant's objectives. The market platform can be seen in Figure 12 (Madina et al., 2020, p. 4).

The Swedish setup can be split into two parts. Firstly, the market platform receives flexibility bids and ranks them in a merit order list. Secondly, the flex tool is responsible for calculating the required volume of flexibility. The market is also connected to the mFRR market. Therefore, excess flexibility is forwarded to that market (Etherden et al., 2020, p. 76).

Moreover, several lessons were learned that should be considered in a large-scale implementation of an LFM. Firstly, stakeholder engagement is crucial for the successful operation of an LFM. TSOs, DSOs, aggregators, and flexibility asset owners need to communicate and coordinate in a way that allows everybody to express their needs and to create tools and mechanisms that provide value for everyone. The second lesson learned was that the need for flexibility varies as time passes. Factors for that would be weather conditions and changes in the grid. Additionally, availability payments are essential because it assures flexibility providers to return their investments. On the other hand, only having activation bids at an early-stage project could be unattractive for flexibility providers. Finding the appropriate remuneration for availability and activation payments is also challenging. Another aspect was technical requirements. Many entry barriers were identified in that regard. For example, baseline agreements or data treatment issues were significant for DSOs and flexibility providers. Prequalification for mFRR markets was also considered too harsh and posed a barrier. The last aspect was timing in the market. The flexible assets vary because some prefer to deliver flexibility in the Day-ahead market and others prefer to deliver in the Intra-day market. Therefore, it is essential to incorporate both timeframes to maximize opportunities. The identified lessons can also be considered in different countries or projects in the EU when developing an LFM (Ruwaida et al., 2021, p. 12).

2.11 FLEXIMAR

The goal of the FLEXIMAR trading marketplace is to implement and provide a minimum viable energy flexibility market place prototype. This marketplace is intended for the audience consisting of individual households up to large industrial size consumers and network operators, i.e. not restricted to any predefined energy consumer classes.

An analysis in the project context indicates how the flexibility trading domain is divided to five different subdomains (Consumer/Prosumer Domain, Automated Trader Domain, Market domain, Verification domain, and Shared data domain) with their distinctive responsibilities, actors, functionalities and domain crossing information flows. Naturally, the domains would extend further and new ones discovered especially if various economical and business aspects and their respective actors would be included.

One key focus in FLEXIMAR project was on development of flexible energy resources utilization enabling management methods and systems. As part of this work, for example, an evolution path toward fully flexible, resilient, and digitalized electricity distribution networks was created focusing on the development of adaptive control and management methods as well as compatible collaborative and coordinated market schemes that can enable the improved provision of flexibility services by distribution network-connected flexible energy resources for local (distribution system operator, DSO) and system-wide (transmission system operator, TSO) needs.

Market place environment (, Market domain) includes the market place collecting the submitted trade orders and executing first come first served trade matching to close trades. Also, this provides access to the information sources and messaging facilities. The information sources include machine readable current and up-to-date market information of the market movements, listing of buy and sell offer levels to all participating traders and more detailed and trader related information for the individual traders. The messaging facilities implement two-way messaging mechanism between the trading platform and the traders. The messaging includes the trade offer message reception from the traders; closed trade notifications, error messaging and market price ticker messaging (Vahedipour-Dahrai et al, 2021, p. 2).

FLEXIMAR introduced a local, flexible capacity market (LFCM), which is run on a day-ahead basis. In this way, flexibility transactions are confirmed one day before the actual delivery. In the proposed LFCM, prosumers sell their flexible capacities to the TSO and the DSO. Hence, within the LFCM, prosumers are the leading sellers, whereas the TSO and the DSO are the main buyers. The buyers are permitted to automatically control the flexible resources of prosumers if their bids are accepted. In other words, the DSO and the TSO can constantly follow their flexibility needs in real-time if they had purchased their required flexible capacities from the LFCM in the day-ahead. In real-time, the operators are allowed to activate the purchased capacities fully or partially. The operators may also decide not to activate the purchased flexible capacities if they do not need them in real-time (Shokri Gazafroudi, 2020, p. 3).

3 Drawbacks and Barriers

3.1 Drawbacks of LFMs

Since barriers for LFMs can differentiate, this section deals with the drawbacks of specific projects.

3.1.1 EcoGrid 2.0

Authors in (Heinrich et al., 2020), pointed out that communication between flexible assets and aggregators has been inconsistent because the infrastructure for this project was based on a previous project called EcoGrid EU that are out of date. The mean absolute percentage error (MAPE) was 31% for the service delivery mean absolute percentage error. If faulty communicating participants were excluded from this calculation, the MAPE would have been 18%. Two other uncertainties influence the MAPE. Firstly, there is a baseline uncertainty when estimating the consumption profile of the participants. Different weather conditions, geographical differences among participants, and random behavior are factors of uncertainty in that regard.

Secondly, the aggregator did not receive feedback about the real-time consumption of their portfolios. As a result, aggregators had to estimate the available flexibility from the weather conditions and the time of the day. While testing the realized benefit from activating 36 services, most were of little benefit. However, one activation prevented a network outage, while one activation caused a network outage. The instance where a flexibility activation caused one network outage was during a baseline service. Outages of this nature can be avoided if the baseline service duration is longer. The rebound effect was 1 hour long when the outage happened. When the rebound time was extended to 3 hours, outages caused by this service could be avoided (Heinrich et al., 2020, pp. 21-24).

3.1.2 Interflex

In the Interflex project, two approaches were tested: the integrated and market-based approaches. To meet every need of the DSO, both approaches must be implemented to some degree. Regulation is one of the main barriers to the integrated approach that makes the DSO the aggregator. In most European countries, the DSO is not allowed to control behind the meter assets directly. On the other hand, the market-based approach, has problems assuring that flexible assets are available when required. (Dumbs et al., 2019, p. 2).

Moreover, the risk is managed mainly by the DSO. Risk should be distributed more evenly, especially for aspects the DSO cannot control, like the inactivation of specific resources. Another challenging aspect is the creation of a market that is liquid and safe in supply (Dumbs et al., 2019, p. 5).

3.1.3 Parity Hybrid Model

The main drawbacks identified for the Parity Hybrid Model are lifestyle and administrative issues. Firstly, the lifestyle aspect, several market participants do not want to participate in the market model. Eventually, due to high complexity with a low perceived benefit. Secondly, the administrative issues, regulations impact energy market development in a major way. However, not in a positive way. Regulation presents a significant obstacle to innovation in the energy sector. Consistent policy and legal changes are required to raise interest in investment in the energy sector (Pressmair et al., 2021, pp. 14-15).

3.1.4 FLEXIMAR

Some challenges have been identified in the FLEXIMAR project. In modelling autonomous actions there are several barriers for behavior modelling. In addition, flexibility gadgets installation costs remain too much for prosumers. The ambiguity to discern prosumer motivation and double taxation in participating in grid are identified as challenges in prosumer grouping process. Furthermore, the problem in getting the right people involved and not enough monitory incentives are the identified challenges in the centrality of leader prosumers.

3.2 Barriers to the Adoption of LFMs

The following section will outline general barriers to adopting LFMs based on several categories.

3.2.1 Current Lifestyles

Firstly, adoption poses a challenge for LFM. Adoption generally begins with a small user group utilizing the new technology until more and more people embrace it. Along the adoption procedure, the participants' technology and expectations change. Therefore, the main challenge of adoption is to satisfy the changing needs and desires of the participants (Pressmair et al., 2021, p. 15).

Moreover, the participant could be disappointed in the emerging technology because their expectation were too high. Projects must keep improving and please the participants to avoid a decrease of their interest. Additionally, the concept of LFM is not popular and mature enough. Along with that goes the lack of expertise of LFMs. People do not grasp the complex nature of these markets (Pressmair et al., 2021, p. 15).

3.2.2 Administration

Existing regulation is an important restricting aspect for LFMs. New regulations are mandatory for innovation to be made in the energy sector. Because, existing regulation cannot support the new structure of LFM. The most barriers are around the aspect of regulation. In that regard, market participants like the DSO are heavily regulated. They are restricted from operating in a market or even being a market operator. Moreover, incentives are not set effectively to support LFMs. For example, energy tariffs and funding schemes are not laid out to efficiently run an LFM (Pressmair et al., 2021, p. 16).

3.2.3 Trust

Firstly, cyberattacks that endanger the grid or IoT devices are part of the trust issues of LFMs. Secondly, privacy concerns arise over the operation of LFMs. Thirdly, the reliance on these new emerging technologies could raise trust issues. Due to the immature nature of LFMs, participants must rely on unstable networks or untrustworthy technology in some cases (Pressmair et al., 2021, p. 16).

3.2.4 Technical

The first technical barrier is developing and adopting a system that fulfills every participant's requirement.

Moreover, the frictionless communication of every system component and high availability is required. The development of new algorithms are needed to optimize the operation of an LFM. However, the scarcity of data to estimate the demand represents a barrier. Lastly, the overall maturity of these markets is a significant barrier, especially for developing new technology components. That's why more real-world implementations are necessary (Pressmair et al., 2021, p. 16).

3.2.5 Standardization

With the emergence of new markets, a substantial amount of diverse technology arises. This leads to different technical requirements in numerous areas. Additionally, various business models are proposed, many without previous involvement in these markets. This makes it hard to evaluate the engagement of these markets (Pressmair et al., 2021, pp. 16-17).

3.2.6 Cost

When designing an LFM, costs need to be considered. Besides initial investment and maintenance costs, hidden costs are a significant barrier. Next up, pricing can be a limiting factor, as tariffs may become higher if grid constraints cannot be resolved. Lastly, the obtained margins are expected to be low, which makes adoption unappealing (Pressmair et al., 2021, p. 17).

3.3 Inc-dec gaming

The so-called inc-dec gaming bidding strategy is one drawback of the zonal market with a parallel redispatch market. In a typical environment without a market-based redispatch, energy providers bid according to their marginal cost. An example of bidding on the spot market can be seen in Figure 13 (Hirth et al., 2019, p. 2).

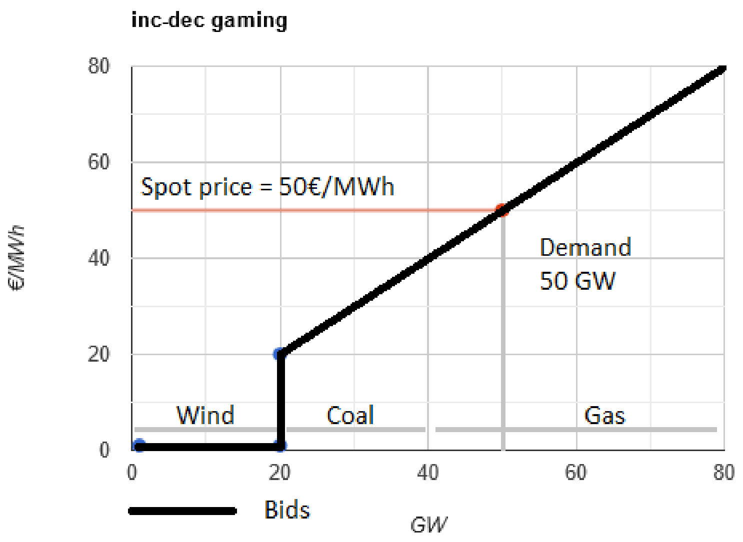

Figure 13 Spot Market Bids without Redispatch

However, when there is a redispatch market with the potential to increase profits, the bidding strategy changes. For example, if there is a redispatch market and the price for the equilibrium of the redispatch market is 60€/MWh in the south of a country and 30 €/MWh in the north of a country, the bids on the spot market change. Powerplant owners do not bid according to their marginal costs anymore. Powerplant owners from the south will bid 60€/MWh because they look forward to selling at this price on the redispatch market. In return, power plant owners from the north bid under their marginal cost at 30€/MWh, so the spot price is 60€/MWh. The powerplant owners from the north would then sell power in the spot market to buy it cheaper at the redispatch market. An example of this can be seen in Figure 14 (Hirth et al., 2019, pp. 2-3).

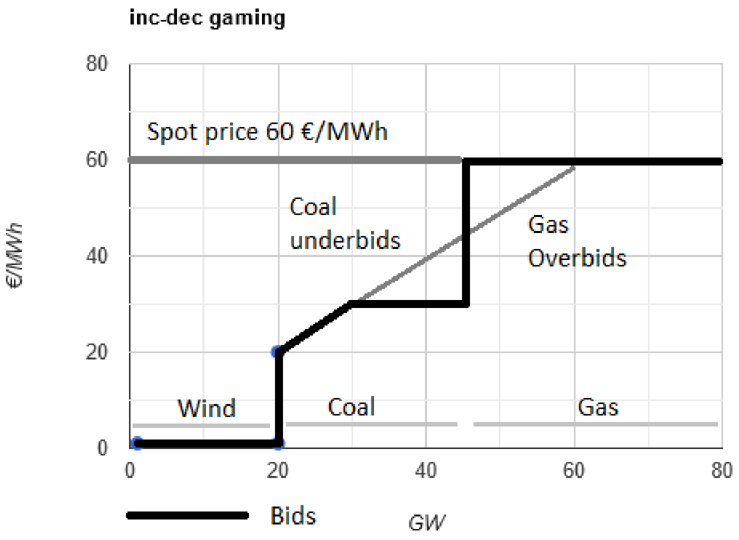

Figure 14 Spot Market Bids with Redispatch Market

These types of arbitrages are common on futures markets. The prices of the two markets also equalize because the arbitrage increases the demand for redispatch. Moreover, the spot market price cannot be adjusted to two prices simultaneously (Hirth et al., 2019, pp. 2-3).

With in-dec gaming come some undesirable consequences. Certain market actors earn higher profits. However, the higher spot market prices and redispatch costs result in a higher bill for the consumer. On the one hand, this market environment creates incentives in the south to invest in new power plants. On the other hand, it creates incentives to invest in powerplants in the north that merely exist to arbitrage and not produce any energy (Hirth et al., 2019, p. 3).

There were instances in history where market actors used this strategy, for example, in the USA and UK. However, regulation around energy markets was changed to prevent that from happening. It is expected that this strategy will not be used in smaller projects because using this method requires investments in analysis and prediction equipment. Nevertheless, implementing this market design on a larger scale would not be desirable (Hirth et al., 2019, p. 3).

4 Improvements

While there are several different projects and fully operational LFMs, research is still ongoing, and many projects are still in development. Moreover, the features and efficiency of existing congestion management approaches lead to various motivations for designing an LFM. After all, it is still uncertain which is the best design. However, this question is not answered quickly, as different market designs suit other intentions. The local differences in circumstances in the energy sector in European countries create different motivations for developing an LFM.

(Dronne et al., 2020, p. 11; Badanjak et al., 2021, p. 6)

4.1 Countries' Different Needs for Flexibility

In the following different characteristics of four European countries are listed.

- France: In France, the depth of congestion is relatively low, while the need for new resource development is moderate. France has one TSO and one DSO. The current congestion management approach is market-based for 90kv and 63kv networks. Apart from these networks, it is connection management based. (Dronne et al., 2020, p. 13)
- Germany: In Germany, congestion is high, most of that being injection congestion. Therefore, the need for new resource development is low. Germany has four TSOs and over 800 DSOs. The current congestion management approach is cost-based. (Dronne et al., 2020, p. 13)
- United Kingdom: The UK experiences both injection and load congestion. one TSO and a few DSO operate in the UK. Congestion management is connection management based, and the need for new resource development is high. (Dronne et al., 2020, p. 13)
- Netherlands: The Netherlands has modest congestion. The need for the development of new resources is high. one TSO and 11 DSOs operate in the Netherlands. There is no market mechanism for congestion management. (Dronne et al., 2020, p. 13)

With that information, energy companies, energy markets, DSOs, and regulators could create incentives to provide flexibility suited to the country they operate in. For example, in Germany, there is high injection congestion. Therefore, mechanisms could be created that curtail in a fair and welfare maximizing way—more about that in section 5.4. Additionally, incentives for smart EV charging, power to gas facilities, and electric appliances like water heaters would be attractive because that would increase downward regulation and decrease the need for curtailment.

In the UK, there is both high load and injection congestion. This means incentives that create a more significant availability of both upward and downward regulation would be reasonable. In that regard, incentives for EV and electric appliances plus residential PV could be created for the general availability of flexibility.

The same incentives could be helpful in the Netherlands because the need for new flexible assets is high in the country.

In France, the urgency for new flexibility assets is only moderate because the depth of congestion is relatively low. However, that does not mean that creating incentives in that country would be completely useless. In general, creating incentives that make society more self-sustaining should be in the interest of every nation.

4.2 LFM Design with Network Constraints

Prat et al. (2021) proposed a design of a continuous LFM with network constraints (pp. 1-6). This is especially interesting because existing approaches disregard network constraints or assume that the DSO is the market operator. However, the DSO is not permitted to act as a market operator in the EU. There are designs of continuous LFM, for example, GOPACS, ENERA, and NODES, but they do not examine network constraints when clearing markets.

4.2.1 Market setup

The market actors (including DSOs and BRPs) send FlexOffer or FlexRequest bids in this proposed market. Moreover, these bids include price, volume, location, and whether they are upward or downward flexibility. In addition, FlexRequest can be distinct between being conditional or unconditional. Due to the continuous market, matching bids are cleared immediately, and non-matching bids end up in the order book until a matching bid appears. When two bids match, the market operator performs a network check before clearing the bids. The bids do not have to be in the same area to match. The network is checked by creating a baseline energy dispatch that looks at existing markets or approximations of load and generation (Prat et al., 2021, p. 2).

4.2.2 Network check

Prat et al. (2021) used a DC power flow algorithm to approach the goal of designing a market clearing algorithm that incorporates network constraints (p.2). It is noted that procured flexibility does not need to be activated. However, the network check must assure that flexibility can be activated without causing congestion. There are two aspects to consider when performing a network check. Firstly, acquired flexibility is not always fully activated, which means that any degree of activation must be assured not to cause congestion. Secondly, the former matches must be considered when checking the realizability of the ongoing match. (Prat et al., 2021, pp. 2-3).

In the following, the different options to examine the effect bids have on the network are listed.

- Individual effect: This option guarantees that every new matching bid pair will not cause congestion while being the only request activated. However, it makes sense that assuming only one matching bid is activated simultaneously, is a restricted approach for the network check (Prat et al., 2021, p. 3).
- Cumulative effect: A different approach would consider all previously matched bids. This approach requires an actor who has an overview of all the matched bids and can activate them if needed (the DSO) (Prat et al., 2021, p. 3).
- All Combinations: By considering the activation of all combinations of previously matched bids, you can guarantee that activating the currently checked bid does not cause network violations. However, this approach requires more computing power the more matched bids there are (Prat et al., 2021, p. 3).
- Unconditional requests: Lastly, unconditional requests can influence previously rejected bids. Since the acceptance of an unconditional bid changes the state of the network, previously rejected bids that would have caused congestion could now be accepted. That means every time an unconditional request is accepted, the order book with previously rejected bids must be re-evaluated (Prat et al., 2021, p. 3).

4.2.3 Case study

Lastly, Prat et al. (2021) simulate such a flexibility market (p. 4). The previously described market setup is applied to a bus system with 15 nodes (or buses). Each bus represents a different location in the network. Every combination of former matches is considered during the network check to guarantee that no congestion occurs. Moreover, bids can be matched partially. Once an unconditional request is accepted, the order book is re-evaluated (Prat et al., 2021, p. 4).

Prat et al. (2021) use two algorithms to accomplish this simulation, one for calculating the maximum quantity transmitted between two buses and the other for clearing the market (pp.4-5). In the simulation, six FlexRequests are sent as a batch, and six FlexOffers come in at a time (Prat et al., 2021, p. 4).

As a result of the simulation, one offer was partially matched, and the rest was forwarded to the order book because it would have caused congestion. Another offer was rejected completely because congestion could be caused by its activation. The remaining offers were cleared normally (Prat et al., 2021, p. 4).

4.2.4 Aspects for Further Work

For the network check, a DC power flow approach was used for simplicity. However, this comes with some drawbacks, one of which is that reactive power flows must be contemplated. Moreover, Prat et al. (2021) assume, on the one hand, that the market operator knows about the baseline dispatch and, on the other hand, that for every FlexRequest, there is a location annotated (p.5). Both assumptions require the estimation of scenarios. That is why the market clearing algorithm could be improved to be probabilistic. The allocation of reserves could also be beneficial in case a surprising event happens (Prat et al., 2021, p. 5).

Further work should also consider block offers that reach over several timeframes. Additionally, the integration of existing market structures and the exertion of market power could be examined in further work. Lastly, this proposal uses pay as bid pricing method. Other concepts, where the market operator could be reimbursed the difference between FlexRequests that are higher than FlexOffers, would be interesting to observe. The market operator’s profit from this concept could be used for investments in the grid or other plans. (Prat et al., 2021, p. 6).

Lastly, further work could examine how an algorithm that considers network constraints could be implemented in existing LFMs (Prat et al., 2021, p. 6).

4.3 Fair and efficient flexibility markets

In many LFMs, aggregators aggregate small-scale RES and flexibility devices to help the DSO with congestion management. To change the behavior of specific flexibility devices, the aggregator remunerates them to achieve the needed consumption profile. According to the price he must pay, the aggregator offers the flexibility bids to the DSO. However, in some cases, a particular node is necessary for the trouble-free operation of the network. Therefore, aggregators near the node could increase their bids, knowing the importance of their flexibility. To counter this issue, Tsaousoglou et al. (2020) propose a market mechanism that encourages aggregators to report their honest flexibility costs and not increase their bids strategically (p. 1-11). The typical approach for LFM optimization is social welfare maximization. Yet, this approach mistreats certain aggregators repeatedly to minimize overall costs. To tackle this issue, a fairness maximizing approach is proposed. This is done by maximizing the lowest payment for the aggregators, also called min-max fairness optimization (Tsaousoglou et al., 2020, pp. 1-2).

To implement this type of mechanism, Tsaousoglou et al. (2020) firstly introduce the system model for the distribution model, secondly formulates the problem, and thirdly present and prove a reward function (p. 3-6). An overview of the process and communication between the DSO and aggregators can be seen in Figure 15 (Tsaousoglou et al., 2020, p. 5).

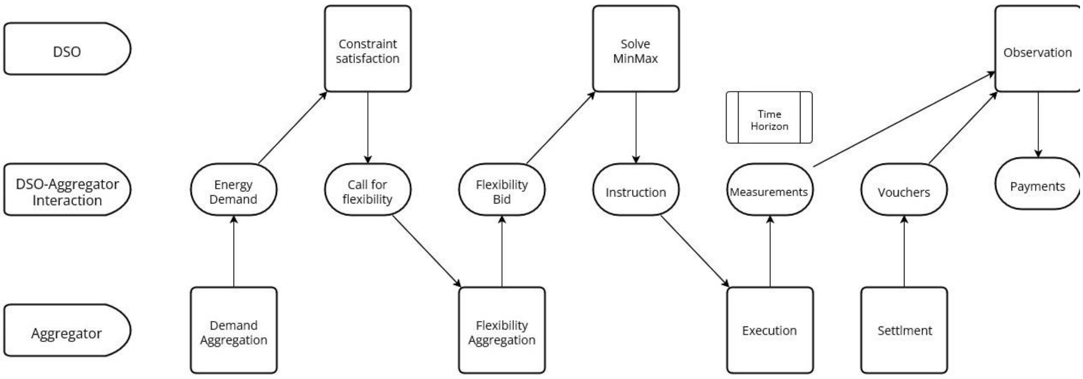

Figure 15 Process and Communication between DSO and Aggregator

In the first step, the DSO receives the aggregator's estimated consumption profiles for a time horizon in the future. After that, the DSO evaluates whether the network will be violated, and based on that, flexibility requests are made. Next up, the aggregator makes flexibility offers. The DSO now has to solve the min-max fairness and give instructions to the aggregators accordingly. The aggregators then change their portfolios to satisfy the instruction. Following this, the aggregator pays for its flexible devices and reports these to the DSO as a voucher. Lastly, the DSO observes all actions of the aggregators and compensates them for the provided flexibility (Tsaousoglou et al., 2020, p. 5).

4.4 Fairness vs. Welfare

Hekkelman et al. (2022) propose a mechanism for local congestion management that considers fairness and welfare (p. 1). Curtailment is used as a mechanism to manage congestion. Hekkelman et al. (2022) describe curtailment as decreasing the prosumption of certain actors (p. 1). The most common way to design a local congestion management mechanism is to focus on welfare. Nevertheless, fairness is another vital aspect because certain actors are impacted differently. To develop a tool that considers welfare and fairness, Hekkelman et al. (2022) first introduce an algorithm that calculates the optimal issuance of curtailment for maximizing welfare (p.2). Secondly, the concept of fair shares is used to create an algorithm that considers welfare and fairness. Actors can then decide whether they want to keep their fair share or participate in an aftermarket that maximizes welfare. Figure 16 shows a visualization of the processes of a hybrid congestion solution (Hekkelman et al., 2022, p. 1-7).

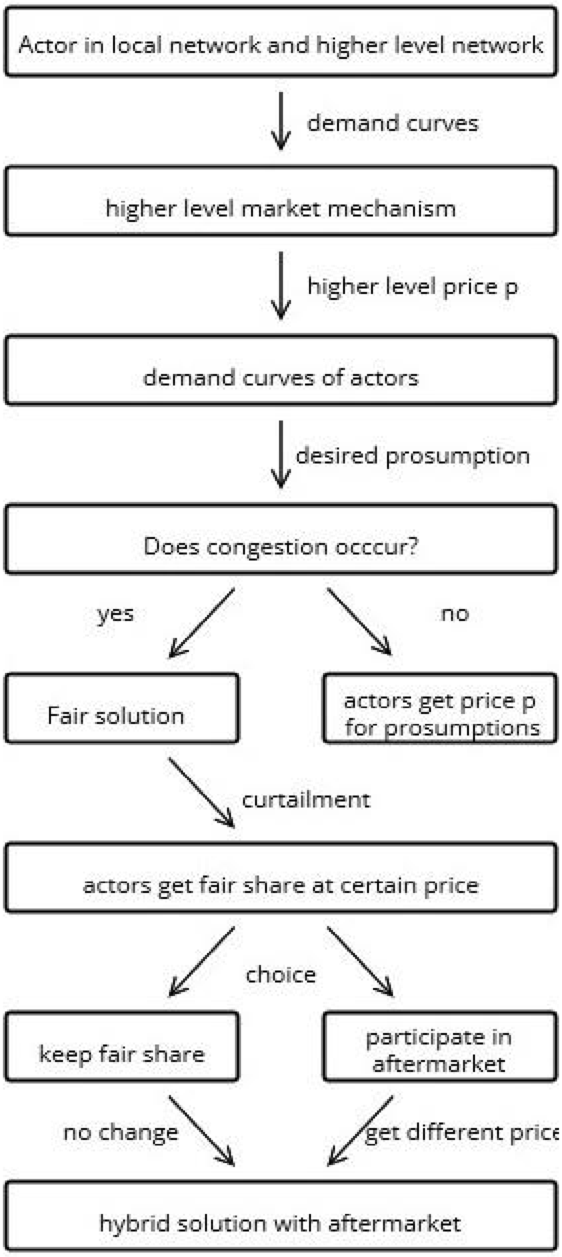

Figure 16 Visualization of Hybrid Congestion Solution

4.5 Enera Hybrid Model

The Enera Hybrid Model considers regulated and non-regulated flexibility assets for congestion management. Under Redispatch 2.0, regulation generation and storage units are remunerated on a cost basis. However, it would be inappropriate to include the non-regulated assets in a cost-based way due to the difficulty of calculating and observing their costs. This proposal allows regulated assets to compete with non-regulated assets using different compensation schemes. Regulated assets are remunerated in a cost-based manner, while non-regulated assets are paid in a market-based way (Sommer et al., 2020, p. 13).

The Enera platform collects the bids from regulated flexibility assets in the first step. The bids are then shown in the local order book. Once the Redispatch 2.0 mechanism determines the dispatch measures, the dispatcher can choose to use the activation of non-regulated assets in the same area instead of the regulated asset. The flexibility from non-regulated assets is acquired in a market-based way through the Enera platform. The Enera order book provides these non-regulated alternatives only if the alternatives are less costly or impact the grid more positively than the Redispatch 2.0 solution (Sommer et al., 2020, pp. 14-15).

The implementation of this proposal is quite simple. The proposal extends the existing design of the Enera platform, and the new Redispatch 2.0 regulation is not violated. Moreover, this proposal can be applied to individual system operators identifying the potential for non-regulated flexibility assets in their area. Another upside of this proposal is that the non-regulated flexibility can be modified to suit the local need. For example, the activation duration can vary according to local conditions (Sommer et al., 2020, pp. 15-16).

A drawback of this proposal is that market-based flexibility is considered after the Redispatch 2.0 selection of flexibility potentials. This drawback can be experienced when the Redispatch 2.0 process considers the curtailment of a conventional powerplant instead of a wind farm, with market-based solutions near the wind farm. Here the best solution would be to use the market-based solution near the wind farm. However, the Redispatch 2.0 process does not consider that possibility and curtails a conventional power plant in a distant area. Another drawback would be congestion occurring in cities. Cities offer a lot of non-regulated flexibility potential. Nevertheless, regulated flexibility is not reachable for Redispatch 2.0. In a later stage, the redispatch mechanism could also consider load, so that load and generation assets can offer flexibility equally (Sommer et al., 2020, pp. 16-18).

4.6 Nodal vs Zonal Pricing

Two main congestion management methods are used around the world. Firstly, zonal pricing, used in European electricity markets, refers to clustering electricity nodes into zones with the same prices. In reverse, nodal pricing may vary at each node depending on the congestions that occur in the grid. In that regard, producers are paid the price defined by their local node.

(Sarfati et al., 2019, p. 1)

4.6.1 Simulation Cases

Sarfati et al. (2019) compared nodal pricing with two types of zonal pricing (p. 1). The two types are available transmission capacity- and flow-based market coupling Zonal pricing. The three pricing methods were used on 6-node and a 24-node case study to evaluate the efficiency and profits of the participants. The 6-node system was divided into two zones with three energy producers, and the 24-bus system was divided into three zones with five energy producers. The producers are spread across different zones also to examine inc-dec gaming (Sarfati et al., 2019, p. 8).

- 6-Bus system: It was observed that the total overloading of lines was the highest in the available transmission capacity zonal pricing, followed by the flow-based market coupling zonal pricing, which had 81% less overloading. The nodal pricing had no overloading. The production cost was also the highest with the ATC zonal pricing, followed by the FBMC zonal pricing, which had 8.6% less production cost. Nodal pricing was the most efficient in that regard. Total profit was the highest for the zonal pricing with FBMC because no congestion appeared, and every producer was paid the price of the most expensive producer. In zonal pricing methods, inc-dec gaming was observed. Therefore, the market operator had positive net expenses in both zonal pricing methods. In the nodal pricing method, the market operator had negative net expenses, which means the operator made a profit (Sarfati et al., 2019, pp. 8-9).

- 24-Bus system: Similar to the 6-Bus system, the ATC zonal pricing has the highest overloading and production cost. FBMC has 76.8% reduced overloading and 14% reduced production cost. Nodal pricing is the lowest in that regard again. The market operator also makes a profit with nodal pricing and a loss with either zonal pricing method (Sarfati et al., 2019, p. 10).

Overall, it was observed that inc-dec gaming took place in both zonal approaches. This resulted in inefficiencies in production and losses for the market operator. The FBMC zonal pricing had reduced inc-dec gaming compared to ARC zonal pricing. However, its efficiency was still 2-5.3% lower than nodal pricing (Sarfati et al., 2019, pp. 10-11).

4.6.2 European Stakeholders’ Arguments against Nodal Pricing

This subsection identifies and examines European stakeholders' main arguments against nodal pricing. Moreover, possible solutions to the arguments are presented.

The first argument against nodal pricing is market power. However, it is not true that nodal pricing is more vulnerable to market power than zonal pricing. Participants in both pricing methods may exploit structural downsides in the grid. To reduce the impact of market power, mechanisms that ease market power were utilized in existing nodal markets (Eicke et al., 2022, p. 6).

Next up, it was argued that nodal pricing hinders flexibility and, therefore, the expansion of RES. In that regard, three worries can be released. First up, it was declared that nodal pricing makes continuous ID trading impossible, which is invalid. Yet it was found that auctions have several advantages. Efficient allocation, high transparency, and pooling of liquidity are some of them. It was also argued that nodal pricing mitigates demand response and energy storage. However, studies show the opposite in the US nodal market. The last point is that grid topology changes are less effective. It turns out that topology changes have a reduced impact on the nodal market. Nodal pricing itself already increases efficiency in the grid. Topology changes are possible in nodal markets but may be more challenging to handle than in the zonal approach (Eicke et al., 2022, pp. 8-9).

The following stated issue was market liquidity. There is more short-term price volatility in nodal markets than in zonal markets. This poses a risk for market participants. To mitigate that risk, market participants can hedge themselves in trading hubs. Locational risk remains but can be dealt with using specific financial instruments. However, some risk persists even with these products (Eicke et al., 2022, pp. 9-10).

Another argument is investment risk. In a nodal market, participants carry the risk of location, distributed among every participant in the zonal market. Additionally, hedging the risk connected to the area is not easy. Nevertheless, this creates incentives to invest in new locations (Eicke et al., 2022, pp. 10-11).

Complexity was also identified as an argument against nodal pricing. Next to the high computational complexity for the price calculation of every node, the pricing rule and the bidding format in Europe also contribute to the complexity of nodal pricing (Eicke et al., 2022, pp. 11-12).

The last argument is the different locational prices. The locational price can affect both consumers and generators. Firstly, the consumer can be negatively affected by a higher electricity price. However, the household energy cost only comprises 31% of the consumer's expenses. The rest is network charges, taxes, etc. Therefore, residential consumers would not be significantly affected. Industrial consumers are influenced more heavily because they pay less network tariffs and taxes. To relieve the consumer, a lower network tariff could be charged. Moreover, policy changes that aim to support industries could be created. Lastly, RES are negatively impacted by nodal pricing. In the case of high renewables generation at a node, low local prices leads to a decrease in renewable generator's revenue. To support RES, regulators could step in and increase subsidies for RES (Eicke et al., 2022, pp. 12-14).

5 Discussion

The concept of LFM is a specific domain and an emerging field that has drawn significant attention among policymakers. Nevertheless, this domain suffers from having an applicable business model in the real world.

Furthermore, each presented real-life business model is in a European country. Since European countries utilize the zonal pricing method, it makes sense that there are no implementations of LFMs in areas outside Europe. For that reason, the finding of this work can only be applied to the European region.

It is difficult for LFMs to have a one fits all solution. Local characteristics, regulations, and participant's needs differ considerably from region to region. Therefore, it is inevitable that new projects that are slightly distinct from their predecessor will arise in that domain.

Various literature and project documentation were examined to answer the research question defined in section 1.2. A concept matrix with an upper category "Local flexibility markets" with sub-categories "Business models", "Drawbacks and barriers", and "Improvements" was built. Each sub-category was again divided into smaller sections that define the concepts. This work examines ten implementations of

LFM that distinguish themselves from another in certain aspects. After that, specific drawbacks of concrete LFMs and general barriers to their adoption are identified. Lastly, improvements for the design of LFMs are stated, and the concept of nodal pricing is considered an alternative to the existing approach.

Consequently, it can be claimed that the objective of this research was to answer the question “What are the proposed business models for LFMs, what are their drawbacks and barriers, and how can they be improved?” was fulfilled.

However, there were several gaps and limitations to this research. These gaps and limitations are addressed in the following section.

6 Conclusion

The literature search provided a broad spectrum of results for LFM implementations, their drawbacks and barriers, and possible improvements. In this work, different design approaches were examined. The main findings were that network scopes from DSO or TSO only to DSO and TSO, flexibility products, various compensation schemes from availability to activation payments, different technical setups, and integration with existing structures are some of the aspects LFMs considerably differ in.

Next up, the critical findings for drawbacks and barriers were that technical difficulties mainly gathered around forecasting and calculation drawbacks. The next challenging aspect is regulation, which dramatically hinders new approaches from being tested and innovations from being made in the energy sector.

Lastly, the main improvements that could be addressed in existing LFMs is explicitly considering network congestion while clearing the market. Moreover, fairness and welfare are essential because they build the basis to allocate resources and remunerate participants optimally. Fairness may be even more significant than welfare when considering a large-scale implementation. When trying to make a business model attractive to many actors, it must be ensured that some actors do not earn significantly more than others. In contrast, certain actors struggle to be profitable. In the end, the nodal pricing method is suggested as an alternative to deal with congestion instead of the zonal pricing method that utilizes LFMs.

There were several gaps and limitations to this research. Firstly, the lack of critical review on existing LFMs was an identified gap in the literature. Many projects did not have literature that explicitly identified the project results or what could be specifically improved for the project. Along with that, the lack of fully operational LFMs also contributed to that. Many projects were merely in the pilot stage and discontinued after that.

Regulation is another aspect that hinders the adoption of LFM. Therefore, the regulation also represents a limitation to the research on this topic. As regulation restricts the development of new mechanisms and designs for LFMs, it also makes research difficult because new regulators frameworks would also promote the development of LFMs, resulting in further research in this domain.

In the end, it will be interesting to see how the adoption of LFMs will play out in the future. Whether large-scale and fully operational projects create an applicable business model that will be determined by regulators and stakeholders' engagement.

For further studies, improving LFMs by considering fairness and network constraints in the market design would be compelling. As the need for integration of RES and congestion management rises, LFMs will also gain attention. The concept of nodal pricing also seems like an attractive concept. However, the EU does have a very rigorous view on that topic. For that reason, nodal pricing will probably not be adopted into European energy markets.

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