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LOCAL FLEXIBILITY MARKETS FOR DISTRIBUTION NETWORK CONGESTION-MANAGEMENT: WHICH DESIGN FOR WHICH NEEDS?

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Abstract

With the growth of decentralized resources, congestion management at the distribution level has become a growing issue in Europe. Several initiatives with local flexibility markets are being implemented, with different designs and objectives. In this paper we provide a comparative assessment of four case studies of local flexibility markets (ENERA, GOPACS, UKPN, ENEDIS) in different countries: Germany, the Netherlands, the United-Kingdom and France. We identify a number of differences across these countries that have an impact on drivers of implementation of these local flexibility markets and their market design such as the type and depth of congestion, the organization and governance of networks operators, the current approach for congestion management and the need for the development of additional flexibility sources. We find that the different market design choices can be explained by the local specificities and use the four case studies to generalize our findings and define a typology of possible approaches for flexibility markets depending on the electricity system local specificities, as well as the sector governance and the policy priorities.

Keywords: Local Flexibility Market; Congestion Management; Market-Design.

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I. INTRODUCTION AND LITERATURE REVIEW

The ongoing decentralization of the electricity sector in Europe (renewable energy sources, electrification of uses, early closures of coal/nuclear power, etc.) creates a number of challenges which would necessitate to allow some "local management" rather than the

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historical centralized management on National or European Level. Among these evolutions, there is growing congestion on both the transmission and distribution networks in some countries. In the United Kingdom for example, congestion management costs increased by 74 % between 2010 and 2017. These phenomena have reactivated discussions about the most appropriate market design to manage congestions, with a "revival" of the nodal vs zonal debate (Verhaeghe et al. 2018).

Distribution networks[4] are also facing several transformations which could create congestion[5] issues and conduct to evolve network management on these networks (CEER 2018). Indeed, the significant growth of decentralized generation assets in distribution networks[6] and increasing penetration of electric vehicles and heat pumps can create constraints on a network historically not dimensioned for these uses (Commission de Régulation de l'Énergie, 2018, Lopes *et al.*, 2007 and Villar, Bessa and Matos, 2018).

In order to deal with congestion issues the Distribution Network Operator (DNO) had historically often made the choice to reinforce the network which required potentially significant investments. These choices were made because levers traditionally used as alternatives to reinforcement (e.g., reactive power management, voltage set point management…) quickly reach their technical limits in the presence of strong decentralized production (Dutrieux 2015). In addition, near real-time management was typically limited to a physical reconfiguration of the network, having no achievable flexibility levers in this time horizon. Integration of DERs at local level is so increasing the need of flexibility in distribution network to solve these congestions.

National flexibility used via historical mechanism to solve congestion was destined to Transport System Operator (TSO) needs and was not destined for congestion-management on distribution level. For several reasons, it may seem complex for the TSO to only extend the traditional congestion-management process for distribution network needs, and interesting to distribution network operator to develop their own mechanisms.

First of all, congestion-management at distribution level seems to be specific compared to congestion-management at transport level. As noticed by (Poplavskaya et al. 2020) in congestion-management, the specificity of needs implies than network operator has not to only consider price of the bid, but also its effectiveness to alleviate network injury. Information about network state, technical characteristics and operational management constraints will be the core of network management. However, distribution network characteristics and topology will differ compare to transport network, with radial topology at distribution level for example. Operational management constraints will also differ at distribution level with considering a very important number of assets with smaller energy capacity, compare to assets connected at transport level. Distribution congestion-management would use different assets, procuring different services than those used on a transport network point of view, to solve congestion emerging from different sources than those at transport level.

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[4] In this paper we defined distribution network as under 110 kV. This classification is important given the variable voltage threshold between European countries to classify networks.

[5] In this paper we use the term « congestion » to refer to all the constraints that may appear on the distribution network

[6] For example, in 2017, 90% of solar production in the UK and 95 % of RES capacity in Germany were connected to distribution network.

Moreover, frequency of congestion-management at distribution level would rise over the year, with decentralization and increasing connection of decentralized renewables assets, but also with electrification of uses, as noticed before. Congestion-management actions on distribution level are yet or would become more and more recurrent.

Finally, congestion-management is a process which would start long-time before real-time, but which need a following management until real-time, to remedy any possible unexpected incidents and have an immediate and direct observation on network's state.

With taking this point into consideration and according to Transaction-cost theory (Williamson 1979, 1981), we can consider than self-management of congestion management by the DSO would be more efficient for two reasons.

First of all, externalizes recurrent specific services would be economically suboptimal because interest of trading will be less important "*as the specialized human (or physical assets) become more specialized to a single-use and hence less transferable to other uses, economies of scale can be as fully realized by the buyer as by an outside supplier*". Secondly, internalization of the process will also allow faster adaptation, which would be necessary for network or process adaptation close to real-time.

It would be then, economically suboptimal to realize congestion-management by transport system operator rather than realize congestion-management by distribution network operator.

Moreover, because of the current responsibility of operators, it seems complicated from DNOs to delegate a part of their network security. As highlight by (Gerard, Rivero, and Six 2016) as grid managers, both TSOs and DNOs are responsible for the security of their respective networks, which involves managing congestion and voltage on their grids. A congestion-management on distribution grid by the TSOs requires than DNOs are giving access and responsibility to solve congestion on their networks but assuming the responsibility of a failure or error from TSOs.

One of the alternatives to historic congestion management is to rethink the use of flexibility sources at a local level. If the penetration of distributed energy resources (DER) can represent the emergence of new grid constraints, it can also be a potential flexibility resource for the network (Kempton *et al.*, 2009, Villar, Bessa and Matos, 2018, Paterakis, Erdinç and Catalão, 2017, Richardson and Flynn, 2011, Acha, Green and Shah, 2010, and Wiechmann, 2017). Various studies show that, in some power systems, the use of local flexibility sources as alternatives to network reinforcement can lead to significant savings for the DNO (Esmat, Usaola and Moreno, 2018, Reihani *et al.*, 2016 and Kotthaus *et al.*, 2019). The Distribution Network Operator should in this frame evolve from only own and develop network (network operator) to realize local energy activations as Distribution System Operator (DSO) (Kufeoglu, Pollitt, and Anaya 2018, and Brunekreeft, Buchmann, and Meyer 2016).

Evolution of market-design is needed to use these new flexibility sources at the distribution level.

There are several elements developed to mobilize the flexibility and solve emerging congestion at distribution level (beside historical which sometimes remains the more appropriate) as network pricing approach, the connection-based approach, blockchain development etc…

In this article we analyze one type of solution, taking the form of a market-based solution, as advised by the Clean Energy Package: a local flexibility market. A local flexibility market will be able to provide services for the flexibility needs inherent to the distribution network operator on model close to the historical ancillary services markets destined to the transport system operator (TSO) but its specificities will be its location and the direct involvement of the Distribution network operator as a buyer (Ramos et al., 2016b)[7]. Such local flexibility market will therefore typically help DNOs to respond to voltage and depth constraints appearing in cases of local energy deficit (load congestion) or surplus (injection congestion). It will participate to solve congestion by optimizing flow into the grid, but the equilibrium between supply and demand would still be manage by the Transport Network Operator on a national level and will not directly be manage by the distribution network operator[8]. In case of structural congestion (i.e. congestion that has been anticipated), the network operator can ask an asset to reduce its injection or increase its load on a network node undergoing an excessive injection peak (injection congestion) for example, or ask an asset to increase its injection or reduce its load for a network node undergoing an excessive load peak (load congestion). A local flexibility market typically involves a selection of assets that can be activated to settle congestion based on an economic principle.

In Europe, we have recently seen the emergence of several industrial initiatives based in this concept of "local flexibility market" including:

- **ENERA (Germany)** : Initiative launched by EPEX Spot (market operator), EWE (energy producers) and the network operators EWE NETZ, Avacon Netz and TenneT focused on the northern area of Germany (Tennet, 2019 and Vassilopoulos, 2019),
- **GOPACS (The Netherlands)** : Dutch platform launched in 2019 by 1 TSO (TenneT) & 4 DNOs (Stedin, Liander, Enexis Groep and Westland Infra) which operates on the Dutch market via the ETPA market platform (Wiersma 2019),
- **UKPN – Picloflex (United-Kingdom)** : Project initially launched by UKPN (a British DNO) whose first calls for tenders were made at the end of 2018 (Do Sam *et al.*, 2019),
- **ENEDIS (France)**: Project launched by ENEDIS (a French DNO) at the end of 2018, with first call for tenders launched in June 2020.

There is a growing body of literature that recognizes the diversity of local flexibility market-designs in theory (Ramos *et al.*, 2016a, Villafafila-Robles *et al.*, 2018, Zhang *et al.*, 2013, Kotthaus *et al.*, 2019, and Gerard, Rivero Puente and Six, 2018). In addition, some papers provide an initial analysis from these emerging initiatives and also highlight the differences in market-designs in practice (Schittekatte and Meeus, 2019, Do Sam *et al.*, 2019, and Radecke, Hefele and Hirth, 2019). A survey such as that conducted by Schittekatte and L. Meeus, 2019, has highlighted the different characteristics of these markets, particularly whether they are integrated within the sequences of current markets, their management via an external platform or not, the presence or absence of capacity payment, the standardization

[7] To define flexibility exchanged on these markets we will use a definition proposed by (Smart Network Task Force, 2015) "The modification of generation injection and/or consumption patterns, on an individual or aggregated level, in reaction to an external signal (price signal/network tariff activation etc.) or in order to provide a service within the energy system or to benefit the network. The parameters used to characterize flexibility can include: the amount of (active) power modulation, the duration, the rate of change, the response delay, and the location."

[8] In some case DNOs would compensate for imbalance created by their needs of flexibility for congestion-management.

of products in these local markets, and the issue of TSO / DNO or DNO / DNO cooperation for these markets organization.

While the existing literature describes some of these initiatives and their diversity of designs, so far little attention has been paid to the analysis of the link between the local electricity system technical and organizational / governance specificities and the choice of design for these markets. These local specificities include the type and depth of congestion, the dynamic of development of flexibility sources, the organizational structure and governance of network operators, and the current approach for congestion management.

The objective of this paper is to provide a structured analysis of the diversity of market-designs for local flexibility markets in the light of these local specificities. We focus our analysis on case studies in four countries (Germany, the Netherlands, the UK, and France) to analyze how the local specificities and motivations to develop a local flexibility market led to a different market design. This allows us to generalize our findings, define a framework for identifying a typology of potential approaches and analyzing the suitability of different market designs for flexibility platforms depending on the local specificities of the electricity system and organization. Indeed, our approach allows us to first characterize the needs that can motivate the setting up of a local flexibility market, and then to understand the diversity of approaches depending on the local specificities encountered and the objectives pursued by each.

The paper is organized as follows. We first identify the different characteristics of electrical systems and their organization and governance that could explain the different drivers of the implementation of a local flexibility market (section 2). In a second step we identify the main market design differences through an analysis of the four case studies listed above (section 3) and emphasize how differences in local characteristics can explain differences in market-design (Section 4). Finally, we conclude by generalizing our findings, identifying a typology of potential approaches and analyzing the suitability of different market designs for flexibility platforms depending on the local specificities and discuss some areas for further investigation.

II. LOCAL SPECIFICITIES LEAD TO DIFFERENT APPROACHES FOR CONGESTION-MANAGEMENT AND FOR THE POTENTIAL ROLE OF LOCAL FLEXIBILITY MARKETS

In this section, we introduce the relevant features characterizing an electrical system which will allow us to explain or understand the characteristics and motivations of certain local market design choices.

2.1. A variety of situations and approaches for congestion management in different European countries

In this article we consider as distribution networks all the networks having a voltage lower than 110 kV. Note that the definition of distribution network (and therefore the division of responsibilities between the transmission system operator and the Distribution network operator) is not homogeneous in all European countries. Table 1 shows the perimeters of different network operators for each country under study. Except in the case of France, Distribution network operators cover networks with a voltage level of less than 110 kV.

Voltage level /**Countries**	**Germany**	**The Netherlands**	**United-Kingdom**	**France**
132 - 400 kV	TSO	TSO	TSO	TSO
110 kV-63 kV	DNO	DNO	DNO	TSO
50 kV -230 V	DNO	DNO	DNO	DNO

Table 1: Perimeter of network operators in Europe

We use the following key distinctive features to structure our analysis of the four case studies, which we detail further below:

1) the type and depth of congestions;
2) the existence and dynamic of development of enough flexibility sources adapted to the needs of the DNO;
3) the diversity of organizational structures; and finally
4) the different approaches and mechanisms for the management of current congestion.

We apply this framework to characterize local situation in the cases of Germany, the Netherlands, the United Kingdom and France and to identify local flexibility market motivations.

2.1.1. *Type and depth of congestions*

The type and the depth of congestion in an area will differently motivate the development of a local flexibility market. Indeed, given that congestion is the "problem" that a local flexibility market is supposed to solve, understanding the type and the size of the "problem" is therefore necessary to explain motivation and design choices.

Assessing the type and the depth of congestion for a region is not an easy task. Congestions, and in particular congestions at the distribution level, strongly depend on specific state of the network at the local level and on the historical evolution of network investments and network users (classic load, RES, EV, HP, etc.). Over a large region (like a country in Europe) different congestion situations may co-exist. In this section, our objective is to give a general trend concerning congestion based on available information.

Different types of constraints[9] must be monitored in a network but here we divide congestions on two mains categories:

- injection congestions (e.g. too much injections compare to physical limit of network assets with integration of RES for example) and
- load congestions (e.g. too much load compare to physical limit of network assets with electrification of uses as electric vehicles charging for example).

Depending on the countries, the type of congestions more spread out on the national distribution network will differ. We observe that in Germany (Joos and Staffell 2018), in the Netherlands (Energieonderzoek Centrum Nederland (ECN) 2016) and to a lesser extent in France (Enedis 2019) congestion will mainly provide from injection problems with an

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[9] Power intensity constraints (that is, the electrical power flowing on the lines, cables and transformers must be less than the maximum depth supported by these networks components), and voltage constraints (i.e., the voltage level in the different nodes of the network must remain within acceptable ranges)[9] (Dutrieux 2015)[9].

increasing share of renewable energy sources (RES) directly connected to distribution network. In the United-Kingdom congestions (in the areas manage by UKPN on which we are focus) constraints will be created by both load and injection constraints (Do Sam et al. 2019).

The depth of congestions will also differ depending on countries, with some already facing important amount and recurrent congestions, when others are only facing sporadic and low level of congestions. We observe in Germany (BNetzA 2016), United Kingdom (Carbon Trust and Imperial College 2016) or the Netherlands to a lesser extent (Energieonderzoek Centrum Nederland (ECN) 2016) than congestion management is already a major issue with significant and growing costs. In Germany, even if the high cost of congestion management is mainly attributed to problems in the transmission network, Schermeyer, Vergara, and Fichtner 2018 show that 86% of the curtailed energy would actually be for problems on the distribution networks and especially on the interface between the distribution and transmission network. Indeed, the prospective cost of distribution network development to accommodate renewable insertion is between 27,5 and 42,5 billion euro by 2030 (Brunekreeft et al. 2020). In the United Kingdom, congestion on distribution network are already present and are plan to increase in the future (UKPN 2018). The prospect of increasing congestion (both injection and load) in the UK, especially on the distribution network, can be implied by the estimation of network investment avoided thanks to the deployment of local flexibilities. Carbon Trust & Imperial College estimates that the implementation of flexibility could avoid between 4 billion and 13 billion in investments for the distribution network by 2050 (Carbon Trust and Imperial College 2016). In France, on the other hand, the prospective studies on the electrical system as well as the demonstrator project currently carried out conclude with much more limited needs in terms of volume of congestion and costs than in the other countries (Enedis and ADEeF, 2017, ECUBE, 2017 and InterFlex, 2017).

A high level of congestion is clearly a motivation to implement a new local flexibility market. In an area with an important level of congestions (which appears frequently), the potential benefits bring by a market may overcome implementation burden. Indeed, competition and direct economic comparison that the development of a local flexibility market could bring, would help to rationalize and possibility reduce high cost of congestion management by network operators. Conversely, the implementation of a local flexibility market may not be worthwhile in a country with light and very sporadic congestions. Motivations would also differ from a zone mainly impacted by injection congestions to an area affected by load congestions. In the first case, the main role of a local flexibility market will be the organization of RES curtailment management whereas in the second case the market should ensure the development or organization of demand response or local generation.

2.1.2. *Existence of local flexibility and need for development of new flexibility sources*

The dynamic of the developments of local flexibility sources has an impact on the motivations for establishing a local flexibility market. Indeed, the existence of an already sufficient level of flexibility sources suitable to limit congestion on a cost-effective way or the necessity to develop new ones will influence motivations to develop a local flexibility market.

Resources already available to provide flexibility are observed in many different areas (Netz et al., 2019, Li et al., 2016 and Zhang et al., 2013). In the Netherlands or Germany, for example, it is estimated that the field of flexibility is already important. The biggest source of flexibility in Germany[10], already in the system, that will allow to solve increasing injection congestions is curtailment of renewable sources.

Even if the current deployment of flexibility resources, the future need for flexibility is such that some areas will seek to motivate a greater development of new flexible resources. An important issue in the United Kingdom, for example, will be to avoid or postpone expensive network investments by using existing flexibility sources, but also by making new ones emerge. A prospective study indicates that the arrival of flexibility will thus save between 4 and 13 billion pounds in terms of network by 2050 but as opposed to a scenario for which no source of flexibility would be used by the network by 2050, which would generate an additional cost of 9 billion pounds (Carbon Trust and Imperial College 2016). Load congestions (created for instance by increasing electricity consumption, heat pumps, EV fast charging stations) are more likely to imply the development of new source of flexibility. In France, the challenges of using and developing flexible assets for the DNO seem less important. A study conducted by ECUBE for the Energy Regulatory Commission concluded that most of the half of future flexibility needs can be fulfilled by already present technologies (e.g., injection congestions caused by RES generators can be solved by RES curtailment, load injection can be solved by already developed demand response) (ECUBE 2017).

Given diversity of situations concerning the existence of sufficient flexibility sources (or conversely the need of investments in new flexibility assets), the motivations for a local flexibility market will differ too.

In some areas with high level of congestion and enough flexibility assets available, local flexibility market will be driven by the willingness to optimize the "dispatch" of already existent local flexibility sources by allowing a direct comparison between all flexibility sources available and allow the DNO to choose the most cost-effective solution. The focus here will be on proposing a transparent and based on economic merit-order remuneration to ensure an efficient dispatch of the assets. (see section 2.1.4).

In other areas, a local flexibility market will be driven by the objective of the development of new flexibility assets. Here, the focus will be on investment incentives, long-term price signals and on the coordination of DNO flexibility need and flexibility sources availability in the area (Hansen and Percebois 2010b). It will be particularly relevant for areas where the level of congestion is high and there are not enough efficient flexibility assets available so far.

2.1.3. *Organization and governance of the network operators*

The organizational structure of the network operators (defined here as the number of operators, their perimeter in terms of tension level and the number of physical interfaces between them) is another aspect that should be analyzed to understand the motivation and design of a local flexibility market. In fact, different organizational structures will determine the level of communication and coordination needs between DNOs and TSOs to organize

[10] Other sources of flexibility already in the system have been reported. For instance, it is estimated that only on the perimeter of ENSO NETZ, a DNO in the eastern part of Saxony, the use of 16,000 water heaters at night can give 370 MW of flexibility on a perimeter with a consumption peak of 1200 MW (Netz et al. 2019).

congestion management and to properly operate their networks and therefore the potential role of a local of flexibility market.

Distributed generation connected to the distribution grid and the development of local flexibility sources tend to modify the historical relationship between TSOs and DNOs and significantly increase the need for data exchange, communication and coordination between them (Gerard et al., 2020, European Distribution network Operators for Smart Networks, 2015, Lopes et al., 2007 and Ampatzis, Nguyen and Kling, 2015). Several examples can be mentioned to illustrate the need for exchange and coordination: The flexibility activation by the DNOs on their own perimeters will impact the overall balance of the system managed by the TSO. Also, the uses by TSOs or other DNOs of flexibility sources on the perimeter of a DNO, would create a network imbalance on the DNO perimeter. Finally, competition between the actors would occur if different actors (TSO or DNO) wish to use the same resource (this scenario will appear even more when DNOs work in tandem).

Transaction costs or communication /coordination needs depend on the organizational structure of the network operators. Due to the existence of non-zero transaction and coordination costs, bilateral coordination between a high number of stakeholders could be costly (Arrow 1969, Williamson 1979, 1981). Indeed, with presence of transaction cost, it could be more cost-effective for small DNOs to participate to a decentralized market shared with others DNOs than to construct their markets on their own (Grossman and Hart 1986). Following this rational, organization structure composed by a high number of DNOs/TSOs and with several interfaces correspond with cases with high communication and coordination needs and transaction costs. Figure 1 illustrates different types of possible organizational structures placed from left to right according to their need for coordination and exchange.

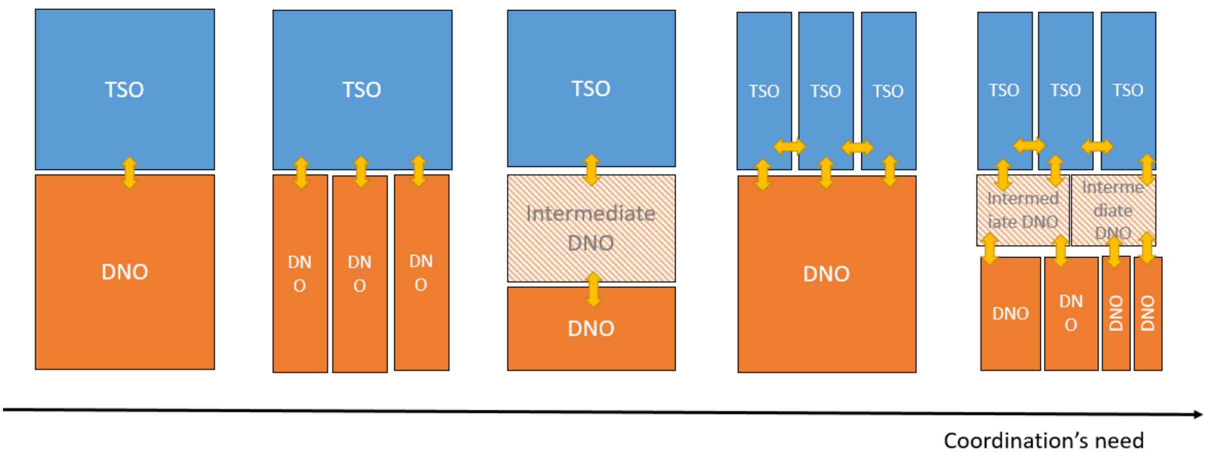

Figure 1: Types of possible organizational structures and need for coordination

The organizational structures of network operators are very diverse in Europe. In Germany, for example, there are 4 TSOs, and around 880 DNOs (JRC 2019). Communication and coordination needs can also be observed between the different DNOs, since certain zones are managed in tandem by several DNOs that officiate at different voltage levels. In France there is only one TSO and a DNO (ENEDIS) has a very large majority and covers 95% of consumers. In the United Kingdom and the Netherlands there are respectively 7 and 8 DNOs.

As a local flexibility market could also have the role of platform of coordination, the motivation and design of such a market will differ depending on the organizational structure.[11] In case of many networks' operators involved, development of local flexibility market will be motivated by a need of coordination and centralization of information.

2.1.4. *Differences in approaches and regulation for congestion management*

The characteristics and economic efficiency of current approaches used for congestion management can also bring different motivation to develop a local flexibility market.
In some countries, current approaches to manage congestions at distribution network level lack of transparency and are often only indirectly factoring economic principles. In addition, historical congestion management mechanisms were often designed for traditional providers (in particular conventional generation assets) and those mechanisms are not featured to allow the integration of new flexibility sources with different technological characteristics than the historical assets (e.g., minimum requirements are often perceived as a barrier for new flexibility sources) (Ruz and Pollitt 2016).

There are several ways to manage congestion (Hirth and Glismann 2018): network solutions (modification of the topology or network reinforcement), differentiated network tariffs, smart connection contracts, trade management (an institution is in charge to limit the traded electricity between geographic areas to feasible flows), and redispatching (i.e., the modification of generation and/or load schedules in order to modify the physical flows on the network). Redispatching approaches can be categorized in two types: cost-based redispatching (participants that are asked to modify generation/demand schedules are paid based on audited costs) and market-based redispatching (participants that are asked to modify generation/demand schedules are paid based on proposed bid or on a local market price). A local flexibility market belongs to this last category (market-based redispatching approach). Despite that market-based approaches are encouraged at European level (particularly after the Clean Energy-Package), we observe, so far, a small proportion of these kind of mechanisms applied to the distribution network at an operational level. This can be partially explained by the fact that historical congestion management mechanisms have often been self-constructed by distribution operator as emergency answers in rare case of congestion. The context has now changed in some jurisdictions (increasing of congestions) and historical approaches are showing their limits.

A closer look to the situation of the four studied countries shows here again quite diverse congestion management approaches. Some countries already have market-based redispatching mechanisms for distribution networks but with lack of transparency and not fully open for small assets. In France, for example, the management of the network under 110 kV is shared by both RTE since it operates on networks of 63 and 90 kV and ENEDIS, which cover networks of 20 kV and LV. The current congestion management carried out by RTE is mainly realized via a market-based redispatching mechanism. In the context of redispatching, RTE has two ways to deploy flexibility in order to solve congestion, either via balancing mechanism or through the contractualization of assets via D-1 contracts which are bilateral contracts with producers (RTE 2003). French balancing mechanism ranks a number of offers from flexible sources (with minimum bid of 10 MW) that can respond to the problem according to an economic merit-order of their offers with pay as bid remuneration.

[11] The size of DNOs and their capabilities (resources, technical and market skills, etc.) is another aspect that can play a role that the motivation of a local flexibility market. In case of many small network operators for example it could be complex and time-consuming to build their independent market on their own. A local flexibility market may concentrate resources and benefits from economies of scale.

If the French mechanism is using market-based approach with taking into account economic merit-order to select flexibility offers, it is also, at least as regards redispatching, not entirely transparent, since system operators do not communicate details of the activated offers or the areas concerned by congestion, and do not allow to every asset to participate with its minimum bid of 10 MW. ENEDIS, the main French distribution operator, does not currently have a market-based approach to manage its network constraints, but proposes specific "smart" connection contracts for renewable electricity connection ("contrats de raccordements intelligents"). These contracts allow to a certain extent for the curtailment of the RES producers in case of network constraint (i.e. injection congestions). In other countries, there is mechanism allowing to manage congestion close-to-real time but no market-based approach. In Germany, congestion management on distribution network is mainly carry out by network solution or by cost-based redispatching solution (Bayer et al. 2018). The used cost-based redispatching solution system is "feed-in management", mostly used at transport level but also used by some distribution network operators. This approach manages the curtailment of renewable production (equal or over 100 kW) for network purposes and reimburse 95% of their costs (or guaranteed purchase rates as feed-in-tariff) corresponding to a management close to real time, without vision on the costs of the curtailed assets, without establishing merit order between several available offers for example. It does not allow merit-order with selecting the most economically effective offer[12]. These costs are moreover at the end paid by consumers because these costs are considered as non-controllable and are outside the incentive's regulation (Brunekreeft et al. 2020). In the United-Kingdom, congestion management on the distribution network is now mainly based on network solutions and connection contracts. The English government has introduced a new connection policy for new generation sources called "Connect and Manage", that offers a possibility of accelerated network access (new assets can start generating before the end of the complete connection/network works), making it possible to manage certain injection constraints. In the Netherland, according to the best of our knowledge, there is no market-based mechanism to manage congestion on the distribution network. There is a cost-based dispatch solution system, with curtailment of renewable energy sources in case of congestion, without regard on cost-efficiency of the measure.

The issues of the current approaches can bring different motivation to develop a local flexibility market. In area(s) with already historical market-based approach, motivation could be to correct the lack of transparency or the inefficiency by not integrating certain (small, new technologies) assets which may have a place in the merit-order, create a real level-playing field between different types of flexibility and better integrate new kinds of flexibility. In a context with no market-based approach, the main motivation with development of local flexibility market will be to add market-based tools to solve congestion and optimize dispatch of flexibility assets.

[12] It is important to mention that in the case of curtailment of RES generators under support schemes (feed in tariff or feed in premium), "merit order" can be used following two different objectives. If the objective is to minimize the amount of payment of the DNO for curtailment, the rational of merit order will be based on the level of the feed in tariff/premium (the amount paid by DNO decreases if RES generators with lowest feed-in tariff/premium are curtailed first). If the objective is to minimize economic costs of the system, merit order will be based on marginal cost of each technology (i.e., near zero for wind and PV generators).

2.2. Impact of these local differences on the drivers of local flexibility markets

Table 2 summarizes the main local specificities of the four surveyed countries. The situation is quite contrasted across the countries. The emergence of local congestion may be very important or quite limited. The organizational structure is also varied, with systems with few (and large) network operators and others with many small operators. In general, countries use congestion management approaches at distribution level without clear economic merit-order and complete transparency, although some countries already have limited market-based mechanisms. And some countries have a sufficient number of flexibility sources meeting the characteristics they seek, while others will have to develop new ones.

	France	Germany	United-Kingdom	Netherlands
Type and depth of local congestion	Low congestion	High congestion. Injection congestion	High congestion Injection and Load congestion	Moderate congestion
Organizational structure	1 TSO and 1 majority DNO	4 TSOs & more than 800 DNOs (including DNO in tandem)	1 TSO and several DNOs	1 TSO & 11 DNOs (including 8 over 100 000 consumers)
Current congestion management mechanism	Market-based mechanism for 90 kV and 63 kV networks, deemed not very transparent. Connection management mechanism	No market mechanism. Cost-based mechanism.	No market mechanism. Connection management mechanism.	No market mechanism.
Need for new resource's development.	Medium	Weak	High	High

Table 2: Summary of the diversity of situations in different countries

In summary, our case studies allow us to identify four main motivations that can drive the emergence of a local market of flexibility:

i) Important level of congestion with no historical market-based mechanism to allow DNO to realize an economical efficient dispatch of flexibility assets to solve congestion;
ii) The willingness to give new incentives to develop and invest on new flexibility sources;
iii) Important level of congestion and the presence of multiple stakeholders which need to coordinate their activations and;
iv) The inadequacy of current congestion management mechanisms which does not allow to integrate a substantial number of potential efficient sources for congestion management.

In the next two sections, we turn to the design choices for local flexibility markets. Through the review of the same four case studies, we identify how the local specificities of the different countries reviewed can contribute to explaining the differences in the design of flexibility markets.

III. THE EXISTING LOCAL FLEXIBILITY MARKETS SHOW A BROAD RANGE OF MARKET DESIGNS

In this section we highlight the design versatility of local flexibility markets. We focus on four European initiatives, which have been launched in the countries studied in section 2. The aim of this section is to describe the main structural differences on market designs, which will allow us in section 4 to understand the link between design choices and local situations. We analyze the same our case studies introduced in section 2 of local flexibility markets initiatives (ENERA, GOPACS, UKPN Picloflex, Enedis)[13].

Schittekatte and Meeus (2019) have described different characteristics of local flexibility markets. Our analysis completes their survey and reorganizes design differences following three main dimensions:

- **The timeframe of the design:** some initiatives focus on short-term management and dispatch of flexibility sources around an intraday timeframe, and other on long-term management and adequacy with capacity reservation payment and multi-years contracts.
- **The use of an external or third-party platform:** some initiatives are based on an external platform that centralize information exchanges and communication and ensure coordination while others are based on self-organized market mechanism only managing the need of one operator without explicit coordination with others.
- **The access easiness:** Some initiatives allow a simplified access to new smallest actors compare to some others in the threshold they propose, even if all of them are providing easier access than historical congestion-mechanism managed by TSO.

3.1. Timeframe of the design

The four initiatives differ on the timeframe on which they focus on their market-design. Two of the analyzed initiatives are more focused on short-term management (day-ahead or intraday timeframe, i.e., some hours before real-time), and two initiatives are more focused on long-term needs (one or several years before real-time).

For ENERA and GOPACS the definition of "flexibility" product is intended to respond to congestions identified in the short-term on a day-ahead (DA) or intraday (ID) vision. Network operators (DNO-TSO) identify potential network issues the day before real-time and indicate their congestion management needs at the time granularity that governs the intraday market in their area (for one day, 96 time steps of 15 minutes for the network in Germany and the Netherlands). For GOPACS, the traded product is named Intra-day Congestion Spread (IDCONS) (GOPACS 2019). It is a product that includes an offer to buy and an offer to sell outside the congested area (or vice versa) via the ID ETPA platform. Local flexibility sources in the case of ENERA and GOPACS are only paid on activation.

In the case of UKPN and ENEDIS, a long-term logic is adopted in the definition of needs (depth and frequency) and adapted products. The definition of planning needs can go up to several years (up to 7 years for UKPN). UKPN & ENEDIS may offer payment for the reservation of flexible capacity (in addition to potential payment if this capacity is activated). Reserved capacity payments are associated to an availability windows (for instance some hours of the day, some months of the year) and can be established for year or even multi-

[13] Most of these initiatives are experimental and are naturally evolving. It is important to note that our comparison is made with the information available to date.

year contract. UKPN can also shortlist assets under development or planned to enable them to integrate more quickly and show in which already-developed tenders they could compete (Piclo 2019).

In conclusion, a local flexibility market may be designed for a short-term vision, focusing on dispatch close-to-real time, or for a long-term vision, focusing on asset investments and adequacy.

3.2. The use of an external or third-party platform

Initiatives will also differ in the coordination they propose for TSO/DNO to ensure system security and mainly to solve congestion. The organization of the local flexibility market is based on an external platform in the case of ENERA, GOPACS and UKPN, but self-organized by ENEDIS.

On GOPACS, TSO/DNO coordination is central. Network operators identify locations where flexibility could be needed to solve a congestion on a part of the network, signify them to an external platform manages by a third-party (GOPACS) that centralizes the needs of network operators and manages potential conflicts and problem in actor’s activations. The GOPACS technical platform does not receive flexibility offers; it is just the link to the ETPA ("Energy Trading Platform Amsterdam") market platform and checks whether the activation of the offer(s) (previously located offers) can be used to settle congestion. If transport network operators can use assets connected to distribution network to solve their own needs, each network operator will remain responsible of congestion-management on their grids. The matching of an offer to buy and sell on this location will be realized (via the product IDCONS) and if there is a spread in price between the two it will be compensated by the network operator.

ENERA platform collect, as third actors, flexibility needs from few DNO and TSO, and flexibility offers from suppliers. However, coordination between DNO and TSO to avoid unappropriated activations is done manually via a process parallel to the EPEX platform. The implementation of the EPEX market platform has revealed the need of more technical coordination. The members of the project would like to evolve in the future towards integration/centralization of the process, in order to filter the offers from one DNO perimeter that could cause a network problem on the perimeter of another TSO/DNO.

For the UKPN case, the external market platform Piclo Flex centralizes the organization of the different tenders following the needs expressed by UKPN (and the other DNOs). During the activation phase, no specific mechanism is provided to manage direct coordination with other network operators such as TSOs. UKPN only warns the TSOs when it intends to activate a flexibility resource but does not request validation from them. The activation is therefore entirely in hand of UKPN and is carried out by the flexibility provider on request of the network operator.

Finally, for the French case, local flexibility reservation tenders are directly organized by ENEDIS (no external platform). Activation is done directly at ENEDIS request, and, for the moment, there is not explicit procedure concerning the coordination with the TSO (this subject is still object of discussion and therefore possible evolution).

In conclusion, a local flexibility market may be designed to coordinate several stakeholder’s actions and information (via an external platform) or to realize autonomous management.

3.3. Access easiness

The access easiness of different initiatives depends on the design of the local flexibility markets. Even if all initiatives are open to aggregators, specific access rules may allow the participation of small assets and new technologies. Because local flexibility market for DNO is a new process, some initiatives will help to integrate new assets by establishing easier participation criteria.

ENEDIS, ENERA and GOPACS proposes an average accessibility for DERs. On ENERA products are standardized on the type of offers made in intraday with minimum bids of 100 kW. For GOPACS the minimum bid size depends on each market-platform linked to GOPACS (500 kW for ETPA) and should be standardized to fit with traditional market-platform requirement. ENEDIS have imposed a minimum offer of 500 kVA, which could be considered as average accessibility (compare to UKPN for example) but it is still representing an important reduction compare to current threshold of congestion market-based solution (10 MW).

The design of UKPN initiatives is more focus on the access easiness. UKPN, on their side, have established different threshold for the offers, depending on voltage level, but is at minimum 10 kW for low voltage call for tenders. They now also giving access to congestion management for many assets connected to distribution grid not integrated in historical balancing mechanism for TSO (Joos and Staffell 2018). They can also shortlist assets under development or planned (Piclo 2019).

Local flexibility market would so be designed to facilitating access to new kinds of assets than historic congestion management or keep entrance's criteria close to historic mechanisms.

3.4. Synthesis of the main market design's differences

A market-based solution taking the form of a local flexibility market is being implemented in several countries to respond to the increasing congestion encountered by Distribution network operators. But we observe that their design can be heterogeneous, mainly on temporality (long- or short-term focus), coordination and organization proposed on the design (the use of an external platform and more or less cooperation for TSO & DNO for example), or access easiness (establish low entry barriers for new participants). Table 3 summarizes how each initiative differs on these three mains targets.

/ Project	ENERA	GOPACS	UKPN	ENEDIS
Temporality	**Short term focus.** (No capacity remuneration. D-1 planning done by the DNOs)	**Short term focus** (D-1 planning. No capacity remuneration)	**Long term focus** (for up to 7 years. Capacity remuneration).	**Long term focus** (product up to 2 years. Possible capacity remuneration.)
The use of an external or third-party platform	External (market) platform managed by a third party actor (EPEX) for few DNOs/TSOs needs. Manual TSOs/DNOs coordination in parallel of the platform. **Middle coordination**	External (technical) platform for several DNOs/TSOs. TSOs/DNOs coordination within platform. **Strong coordination**	No explicit coordination mechanism. **Low coordination**	Self-manage call for tenders. Coordination method with the TSO not yet established. **Low coordination.**
Access easiness	**Average accessibility**. Minimum offers of 100 kW	**Average accessibility.** Minimum bids of each platform (0.5 MW for ETPA)	**Easy accessibility**. Minimum offers of 10 kW.	**Average accessibility.** Minimum Offers: 500 kVa

Table 3: Summary of the main features of the different initiatives

IV. JOINT-ANALYSIS OF LOCAL MARKETS AND SPECIFICITIES: WHICH DESIGN FOR WHICH NEEDS?

This section presents the joint analysis between the local specificities of the four analyzed countries (section 2) and the design of market initiatives in these countries (section 3). This analysis allows to understand the choice of design resulting from the objectives and specificities according to each situation. In section 2, we have illustrated the diversity of situations in European countries and shown that the local differences can explain four different drivers to develop a local flexibility market. In section 3 we have highlighted the various market design approaches for tense flexibility markets. By crossing our analysis of the local characteristics and of the design specificities, we identify four situations that could lead to different market-design choices which we discuss in greater details in the next subsections:

i)The need for short-term design to optimize the dispatch of flexibility assets;

ii) The need for long-term mechanisms to develop new assets and services;

iii) The need for an external platform to manage communication and coordination between TSOs / DNOs;

iv) The willingness to minimize barriers to entry of congestion management mechanisms in order to facilitate the integration of decentralized resources into the system.

4.1. The need for a transparent merit-order to optimize the dispatch of flexibility assets

Depending on local characteristics, a design allowing a clear merit-order between existing flexibility assets for the dispatch will bring an important gain of efficiency for the short-term congestion management.

In some areas, the level of congestion is already high and main sources of flexibility are in the system, but current congestion-management mechanism does not optimize the dispatch of these sources with a clear economical merit-order. As we have mentioned in the introduction, DNOs have a great visibility on their network's needs, but sometimes they have a lack of visibility on the possibility and cost of the decentralized assets connected to their networks, especially on short-term aspect with already developed assets.

A design as developed by ENERA for example, which proposes a clear short-term merit-order on a market-based principle for flexibility assets to network operators, with a transparent platform would allow to increase efficiency on the dispatch and uses of flexibility assets in Germany.

In principle, well-designed short-term markets make the best use of existing resources (Stoft 2002). Today, with no competition between assets and economic efficiency with using only network measures, it does not allow the best use of existing flexibility resources.

4.2. The need for stable and long-term signals to encourage the development of new flexibility sources

In some areas where we observe an already important or increasing perspective of congestion, the number of flexibility sources could be not sufficient or not adapted to the type of congestion. In this case, it may be necessary to develop new flexibility sources to propose services for congestion management to DNO. To provide incentives for development of efficient flexibility sources, local flexibility market-design should focus on long-term timeframe, providing stable and long-term signals via capacity remuneration payment and/or long-term contracts.

In our example, the design chosen by UKPN via Piclo Flex platform, fits well in this direction. They realize need's plan and contract up to seven years, accepting not already developed assets in their call for tenders, but also by providing payment for energy and capacity.

Because investment is made on long-term purpose market-design should give with long-term timeframe will be privileged (Cramton 2017). As described before, if competitive market will drive short-term efficiency (using existent flexibility sources), long-term oriented market design will should attract the most efficient actors and reduce the flexibility investment and financial costs on a defined area. Need's definition, plan and contract on several years for example will give a better visibility and reduce risk for investors. The market can also provide better long-term vision on revenue for investors by combining a payment for activation (energy) and for reservation (capacity), thus reducing the risks for investors by having a less uncertain vision of the profitability for an asset than in local flexibility market made on a traditional intraday timeframe.

4.3. The need for an external platform to improve the coordination between system operators and other stakeholders

The need for coordination, communication and data exchange would be high in a context with high level of congestion and important number of stakeholders involved with varied sizes (Section 2), local flexibility market which are focusing on coordination between stakeholders will be privileged.

As exposed, in some areas the number of TSOs/DNOs can be important. As we have mentioned in introduction, a congestion-management by the transport network operator of needs on distribution network operator could be sub-optimal considering transaction cost theory. The need to coordinate actions made separately, even if each network operation will remain responsible of congestion-management for their own grids, would also generate inefficiency. Indeed, there will be an important need to coordinate recurrent actions for congestion management between several stakeholders, which would so motivate DNOs to develop a local flexibility market to provide a coordination tool between stakeholders, and in particular a local flexibility market based on an external platform centralizing data and actions for several TSO/DNOs. Indeed, because networks are inter-connected a flexibility asset could have an interest for several actors, to be used for congestion-management issue for several DNOs or participate to national balancing manage by the TSO for example. If they are not sharing a common-used platform, the hourly coordination of them, would create complexity. Moreover, in case of the asset use is not specific and need of the network operators where is connected the assets is not very recurrent, transaction cost theory explains than it would be suboptimal to consider an exclusive use by a network operator.

As shown in section 3, the coordination that different type of local market platforms may differ. On the cases analyzed here, a platform such as GOPACS which has in these operating characteristics many elements facilitating the communication between TSO / DNO and between DNOs, will facilitate coordination between actors in an institutional context, split between many network operators. The information to determine best value for the system of a flexibility assets will be directly determined by the willingness to pay of each actor. The external platform would also allow to share methods and understand potential issues created by offer activation on their own network. This is a first step towards an external platform having more important technical role.

A local flexibility market using an external platform to centralize data and the needs of each can be used and be more interesting than a multitude of parallel local markets developed by each DNO. The co-construction of a platform between TSOs & DNOs, the communication and centralization of their network constraints, and a joint monitoring of network operators on a local flexibility platform can meet the need to organize and facilitate cooperation between TSOs & DNOs.

4.4. The need to reduce participation barriers to allow new (small) players to value their flexibility for congestion management

In some areas, emerging flexibility sources have difficulty participate to congestion management because of inadequacy of current mechanisms (section 2). Indeed, the existing congestion management approaches may potentially be too restrictive to allow full integration of decentralized resources and adaptation of those mechanisms (historically built for TSO's needs and conventional assets) could be difficult to implement. In this context, local flexibility market-design should focus on access easiness.

From our case study, the designed chosen by ENEDIS fit well to this type of characteristics. The French case illustrate very well thus context since the development of a market is largely driven by the interest to integrate local flexibilities. Indeed, although French congestion needs are currently estimated in the prospective studies to be rather limited (see section 2), existent decentralized assets still want to enter to new markets, even if the revenues estimated for them are limited. Opening markets to all potential providers of flexibility is be seen as necessary in some situations (Villar, Bessa, and Matos 2018). By reducing barriers compared to conventional mechanisms, for example with a minimum bid of 500 kVA (even potentially reduced), it allows decentralized assets to participate.

Market design of the local flexibility market should consider different aspects to facilitate access. It is possible to implement a lower minimum threshold in terms of supply volume as well as less rigid product standardization than historical congestion management mechanisms, in order to also allow actors offering different products to participate. The market should, if possible, not require an exclusivity of the assets and thus allow the assets to participate also in other markets for other products. Finally, penalties should not be daunting not to place too much risk on new assets.

V. CONCLUSIONS

The ongoing transformation of the electricity systems across Europe leads to a range of specific challenges and issues, which are different depending on the local power system and market specificities. Our paper leverages 4 cases studies in different countries (ENERA, GOPACS, UKPN and ENEDIS respectively in Germany, the Netherlands, the United Kingdom, and France) of the emergence of new flexibility platforms to identify the drivers of the implementation of a local flexibility market and the key specific design choices depending on the local context. The main contribution of the paper is to provide a structured analysis of the diversity of market-designs for local flexibility markets in the light of these local specificities.

As a general conclusion, there is no "one size fits all" design to manage congestions: characterizing and understanding the local context and needs before implementing new market or regulatory mechanisms is a prerequisite to ensure effectiveness and efficiency. Local flexibility market which should persists over time to answer to these new needs should have different design depending on each location and could not have a unified development even among European countries. We show indeed that the power system and market context among the four countries is markedly different. The emergence of local congestion, the need to encourage the development of new resources, the organizational framework and the current congestion management approaches differ across the four countries. We highlight how these different local differences affect the motivations for the development of a local flexibility market, and the main contributions than a local flexibility market would have for an area, which include:

- The optimization of dispatch of flexibility assets in case of significant appearance of local congestion on the perimeter of a distribution operator;
- The willingness to send incentives to develop new flexibility sources on a specific location;
- The need for a new coordination tool between several stakeholders, as multiple DNO and TSO, in a context of increasing coordination needs and possible high transaction costs; and
- The willingness to integrate new players, which may face entry barriers by offering products that are different from those used in the national balancing markets run by TSOs for example.

We have also identified a number of key differences in the market-design of the different local flexibility markets surveyed, mainly on three core aspects: the timeframe of the design (short or long-term), the use of an external or third-party platform and their access easiness. Our paper then relates the diversity of situations encountered in the different countries with the market design choices. We use the 4 cases studies to generalize our findings, identifying a typology of potential approaches and analyzing the suitability of different market designs for flexibility platforms depending on the local specificities:

- When there is already an important level of congestion and flexibility assets available, a design establishing a transparent economic merit-order can be useful to optimize the dispatch of flexibility assets and the short-term congestion management.
- When the objective pursued by the local flexibility market is to encourage the development of flexible assets in an area, a design and product definition providing a longer-term predictability of revenues (e.g. with capacity payments) can be relevant.
- A local flexibility market based on an external platform and with centralization of key information can be useful to facilitate communication and coordination in cases with organizational structures involving many TSOs & DNOs and a variety of stakeholders.
- Finally, when the regulatory framework in place is features barriers preventing the flexibility of new smaller flexibility resources from being exploited, a market-design which reduces the minimum participation thresholds in terms of energy can enable the participation of new players.

Whilst this article identifies different motivations of local flexibility markets and how different market designs may address them, it does not cover a number of issues that are left for further research. Because local flexibility markets are only a subset of the potential solutions to manage local congestions, the creation of a new local flexibility markets should be compared with the possibility of extending and improving historical congestion management mechanisms, as well as other policy tools that influence congestion such as network tariffs, connections contracts, etc.

A normative economic analysis framework needs to be developed to compare different approaches to manage flexibility resources at the local level for congestion management. It will be necessary to take into account some of the possible implementation cost associated with the development of these new local flexibility markets, but also handle possible impact of these development on historical mechanism as balancing and more generally on socialwelfare (Hansen and Percebois, 2010b, Madina et al., 2019, NODES, E-Bridge and Pöyry, 2019, and Neon and Consentec, 2019).

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