Article 2: Congestion management in distribution networks: Which market design to integrate local flexibility assets considering information and investment incentives issues?

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June 2021

Abstract: Given transformations of electricity system (e.g., decentralization, high penetration of RES, new usages of electricity), congestion-management in distribution networks is becoming increasingly necessary. To efficiently deal with congestions, distribution network operators should combine classical solution of network reinforcements with the use of well-located local flexibility. In this paper we analyse whether a simple market-based solution (i.e., a local flexibility market focused on activation) is enough to achieve a socially efficient outcome. We argue that the answer is no when taking into account realistic features of distribution power networks: dynamic perspective and network reinforcement indivisibilities but in particular the asymmetric information between flexibility providers and network operator about key aspects of network economics, and the lack of commitment from the DNO. Indeed, under this simple market design, asymmetric information would lead to a significant income uncertainty for flexibility providers, and lack of commitment would lead to potential opportunism issues. Local flexibility market focused on activation with energy remuneration does not provide sufficient and stable information about network operators' situation and willingness. In consequence, this market design may distort investments and result on a socially inefficient outcome. The last part of the paper discuses several options to improve local flexibility markets, including a local long-term capacity auctions to enhance local flexibility assets development and changes in network regulation to ensure better diffusion of distribution network information and appropriate arbitrage between CAPEX & OPEX.

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1 Introduction

The energy transition (e.g., RES) and the new usages of electricity (e.g., electrical vehicles, heat pumps, etc.) increase the solicitation of distribution network and the possibility of congestions (Carbon Trust and Imperial College, 2016, Dutrieux, 2015, Schermeyer et al. 2017).

A congestion[4] represents a cost for the Distribution Network Operators (DNO) which have to compensate the energy which they do not deliver to the consumer or have to respect reliability criteria fixed by public authorities (Stoft, 2006, Cornière *et al.*, 2000).

To limit congestion, DNOs can reinforce their networks' capacity. But network development also come along cost and acceptance difficulties (Spiliotis et al., 2016, Rious, 2007). We currently observe an emergence of more and more alternatives to classical network development. The uses of well-located flexibilities contribute in some cases to manage congestions in a more efficient way. Indeed, development of flexibility assets is an alternative to avoid or postpone network development (Kempton *et al.*, 2009, Villar, Bessa and Matos, 2018, Paterakis, Erdinç and Catalão, 2017, Richardson and Flynn, 2011, Acha, Green and Shah, 2010, Wiechmann, 2017). The use of flexibility assets in a context of increasing congestion could then potentially lead to significant savings for the DNO and then for the social-cost of congestion-management (EPRI, 2013, Esmat et al., 2018a, Reihani *et al.*, 2016, Kotthaus *et al.*, 2019).[5]

In this context, flexibility services and network reinforcement should be considered as substitutes products and will therefore require coordination in their development process. This paper aims at to characterize coordination requirements between local flexibility and the distribution networks and to understand how incentives provided by different market designs (in particular local flexibility markets) may ensure or not this coordination.

Local flexibility markets are emerging in Europe as a way used by the DNO to mobilize local flexibilities.[6] There is a considerable diversity of local flexibility market-designs (Ramos *et al.*, 2016, Schittekatte and MEEUS, 2019, Esmat et al., 2018b, Dronne et al., 2020, Jin et al., 2020). Considering temporality and the way that DNO remunerates flexibility providers, local markets can be classified in two types:

[4] Congestion would refer here to every constraint appearing on distribution network

[5] For instance, EPRI (2013) analyzes cases on distribution network reinforcement in California and concludes that flexibility provided by storage system would defer 5.5 million dollar of investment on the substation for five years with keeping substation peak load under the load target.

[6] Local flexibility market is a market-based solution which is the preferred option in Europe as specified by the Clean Energy Package on the Article 32 of the Directive (2019/944) on common rules for the internal market of electricity. There are other organization possibilities: network users' obligations, network tariffs or connection arrangements (CEER, 2018) that are not analyzed in this paper.

"activation products" for local flexibility markets where flexibility providers participate to specific day-ahead or intraday markets and are only remunerated by the delivered/activated energy (e.g., the case of ENERA) and "capacity product" for local flexibility markets where flexibility providers participates to call for tenders to get a multi-year contract and are remunerated based on this contract (e.g., the case of UKPN).

It is worth notice that every market-design does not provide the same incentives and the same level of coordination, especially considering flexibility assets development. Dronne et al., (2020) introduce the following intuition: capacity tender for reservation of flexibility will provide stronger incentives to invest with more predictable stream of revenues than a market which only provides a short-term activation of resources. Hence in distribution networks where there is a structural need for investment in new flexibility resources, tenders focused on reservation of flexible capacity provide better incentives and coordination signals.

In our article we will *have a specific focus on market-design to provide information and incentives for investment in flexibility assets for distribution network purposes.*

Whereas the related literature do not specifically cover the scope of this paper (coordination of flexibility assets and network development at the distribution level with local flexibility markets), they inform us about the issues and complexity of such coordination.

The literature have discussed the complexity in coordination between network operators and private investors in an unbundled and liberalized power sector, mainly for the transmission networks (P. Joskow and Tirole 2005, Rious, 2007, Conejo *et al.*, 2016, Chao and Wilson, 2020). Chao and Wilson (2020) have especially noted that whereas short-term (i.e., dispatch) coordination has been improved there is a remaining lack of long term coordination (i.e., investment) between network and generators or flexibility providers.

Literature about coordination between the network and flexibility providers at the distribution level is rather limited and mainly focused on locational tariffs design and short-term issues. For instance, some studies explore distribution locational marginal prices (DLMP) as a way to optimize short-term/dispatch DER decisions (Meeus et al., 2020) .

The literature allows us to characterize the mains requirements for investment in electricity generation. Provide the appropriate signal for investment, and ensure long-term efficiency was one of the primary motivation when it came to design market for electricity (Chao and Huntington, 1998) (Stoft, 2002). As remembered by (Cramton, 2017) giving this appropriate long-run price signal is the most challenging part of electricity market-design and have therefore led to many specific mechanisms over the time. The need of specific market-design to face the increasing need of system's flexibility in a line with decentralization have been mentioned by some papers as (Newbery et al., 2018) or (International Energy Agency (IEA), 2016). Closer to our problematic Vogel (2009) who have studied efficient investment signals for distributed generation, notifies the fact than in situations with a single buyer, as the distribution network is with flexibility services, necessity to give certainty to the investors is a key to ensure than "grid operator is not able to withdraw payments which are only announced to attract DG investments."

Summing up, *to the best of our knowledge, there is not research work mainly focused on the impact of market-design on the coordination between distribution network and flexibility assets development.*

The rest of the article is organized as follows. In section 2 we set the problem of coordination between network development and flexibility investment, we develop the economic framework which will allow us to understand why "pure market" solution (i.e., local flexibility market based on activation) do not completely fit for this purpose. We analyse the market-failures and the risk associated to investment on flexibility sources given asymmetric information about key network economics parameters and lack of commitment of this type of market designs.

In section 3 we illustrate this problematic using a simplified model and a numerical example. We first define idealized "first best" world characterized by socially optimal investments (i.e., arbitrage between network development and flexibility investment to minimize total cost) based on an integrated social benevolent planner with perfect information. We especially illustrate the differences on flexibility uses depending on the network cost considered by the social benevolent planner. Then we analyse the same case in an unbundled/liberalized context (network operator is regulated, flexibility providers revenues and investments depend on market signals) with a simple short term local flexibility market where flexibility providers are remunerated only by local energy injected. Potential investment distortions and social inefficiencies are identified by comparing "first best" solution with local flexibility market outcomes.

Finally, in section 4, we discuss market-design options to allow an appropriate level of flexibility sources development for DNO congestion management.

2 Setting the problem and the analytical framework

To solve congestion management issue, classical economics theory explain us than network development would be realised until reaching the marginal cost of congestion (Stoft, 2006). After reaching this point, classical economy considers than a pure market would send the optimal message for flexibility asset development, but without considering many aspects of the "real-world". Classical theory considers for example perfect information sharing, no transaction cost, perfect rationality… But for investment in flexibility assets many aspects will not fit with grid analysis. The literature has widely addressed the complexity of investment in electricity generation and the impact of market-design to answer to these risks have been well covered (IEA, 2019, Roques and Finon, 2017, Finon, 2008, Roques, 2020, de Maere d'Aertrycke et al., 2017, Peluchon 2019, D. Newbery et al. 2019, Henriot and Glachant 2014). It is worth notice than classic economical theory do not always provide perfect answers for these investments.

Analytical framework provided by institutional economics would seem more appropriated to cover this problematic. This framework is based on the existence of opportunism and bounded rationality, and this implies a certain level of transaction costs (to avoid negative consequences, actors will take actions which would engage on transaction cost). In this framework, economic agent would not always take optimal decision in terms of social-welfare optimisation (Williamson, 1985, 2000).

One of the key contributions of institutional economics is that the level of transaction cost depends on the characteristics of assets with varying degrees of importance. Three main factors are used to categorise assets and transactions, define the importance of transaction cost for them and then provide the appropriate governance cost and structure (Williamson 1981): the asset specificity, the uncertainty and the frequency of the transaction. Depending on the characteristics of the transactions, Williamson will advise different organisation solutions from "pure market" to "internalisation of processes".

<table>
<tr><td colspan="2" rowspan="2"></td><th colspan="2">Asset specificity</th></tr>
<tr><td>No</td><td>Idiosyncratic</td></tr>
<tr><th rowspan="2">Uncertainty</th><td>Low</td><td colspan="2">Pure market (neoclassical contracting)</td></tr>
<tr><td>High</td><td>Bilateral governance</td><td>Unified governance</td></tr>
</table>

Table 1: Williamson contracting issue depending on uncertainty and asset specificity (Williamson, 1981)**.**

Considering institutional economic framework defined by Williamson (1981, 1985) several characteristics of flexibility assets and its coordination with distribution network operator would create important transactions costs.

Asset specificity

First, flexibility assets for distribution network services would be considered *as specific assets:* In the framework that we consider, flexibility assets will provide specific services for distribution network operator and would not always or completely be used for other markets. In this context, flexibility assets will be considered as specific for this service. Following this characteristic, a main lack would create important transaction cost, the *Lack of commitment from the DNO***.** The Importance of commitment for some assets have been noticed by institutional economics (Williamson 1985, North 1993). According to (Williamson, 1985), there is stronger risk of opportunism, without commitment, because opportunism is considered as particularly relevant for “economic activity that involves transaction-specific investment”(Williamson, 1979).

In electricity sector the literature have defined the volatile choice from the possible demand, which has no commitment, and the risk taken from supply-side with investment in a capital intensive assets for a long period (Roques and Finon 2017, Moreno et al. 2010, D. Newbery 2016). This lack of commitment would have a stronger impact on local flexibility assets. In the case of flexibility assets for network congestion this risk is even stronger because there is only one buyer, the DNO. There is then a need of commitment for these specific assets by contracting, to reduce potential opportunism from a party, and then transaction cost.

Finally, it is important to notice that the lack of commitment of the DNO may have strong consequences on the revenue stream of flexibility providers. Indeed, a decision of network reinforcement will so often mean a complete or partial disappearance of flexibility sources revenue. As shown in EPRI (2013), in case of remuneration for distribution investment deferral for example, the value of distribution investment deferral services depends on the number of year that an investment can be deferred and on the size of the deferred investment.

Uncertainty

Second, transaction will be considered as *uncertain.* Flexibility assets will be used as an alternative to network development, which means than they would be considered as substitutable products. In this frame, a decision of network development will imply a disappearance of the value for the flexible assets. Moreover development of congestion in the network will be linked to many exogeneous factors, as development of electric vehicles or heat pumps in a specific area etc…

We identify and analyse one main factor which exacerbate uncertainty in this configuration for investment in flexibility assets: *asymmetric information.*

The existence of asymmetric information have been introduced by Akerlof (1970). Author highlight the possible differences of information between actors in a market, and especially the concept of “adverse selection” which represent the inappropriate decisions taken by actors in case of the lack of strategic information.

In our frame, flexibility investors will have a fear of "adverse selection". Impact of lack of information from-demand side on investment have been approached, with notifying the important risk of under-investment (Oliveira 2008, Neuhoff and De Vries 2004). Closer to our problematic, Buchmann (2020) highlights the need of transparency on medium and long-term flexibility services needed by DNOs to be an alternative to network expansion.

Different factors lead to an initial asymmetric information between private investors and network operators[7]*:*

- *First of all, lack of transparency in distribution network key data.* Network cost is not an unique and transparent value because it would be deeply linked to technical and local specificities. The absence of distribution network development plan (as it could exist for transmission network) will also make hard to anticipate distribution's operator decision and to analyse their strategy of network development in case of congestion.
- *Distribution congestion management and network investments are very complex topics*. It is influenced by very instable exogenous components and would be sometimes partially solved by self-management of network operator as network reconfiguration (at no-cost) or necessitate infrastructure development. The cost of network development is also very different depending areas, and are linked to others factors than pure economic (as geology or social acceptance for example).
- *Interactions between network regulation framework and network development choices are very difficult to predict*. Several aspects can lead *to different network's development decision than the social efficient one* and will so be hard to anticipate for deregulated investors. For instance, ineffective Cost+ regulation, which will give more incentive to realize CAPEX than OPEX will lead to suboptimal choice, hardly predictable for deregulated investors because it will lower the effective cost of network development for distribution network operators (Brunekreeft et al., 2020).

This asymmetric information will make complex investment decision in flexibility assets for private investors because they will have difficulty to anticipate network development. Even if all the relevant information is available for flexibility investors, it is not sure that they have the expertise and capacity to put together and anticipate future local prices. As emphasized, network reinforcement and flexibility sources use should be seen as substitutable products for congestion management.

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[7] The problematic of asymmetric information between the regulator and the network operator has for example been discussed by Joskow (2006) or Joskow and Tirole (2005) for transport network. Our focus here is on the asymmetric information between the network operator and the flexibility service provider.

Transactions in a flexibility market will therefore have two main characteristics: the specificity of the assets impacted by the lack of commitment and the uncertainty linked to the asymmetry of information. According to the analysis grid proposed by Williamson and summarised in Table 1, the most appropriate contractual form could therefore be contracts rather than a pure market.

In this article we explore and set the problem of coordination between network and flexibility investments taking into account realistic features of distribution power networks, and in particular the asymmetric information between flexibility providers and network operators and the lack of commitment from DNO. We argue that these aspects create uncertainty and risk of opportunism for flexibility providers and impacts flexibility investments decisions under the local flexibility market design focused on activation.

3 Numerical illustration

Using a simple toy model, this section numerically illustrates properties of different market designs to ensure the coordination between network and flexibility. To do so, market design outcomes are compared to the "first best" social cost minimising solution.

This section is organized as follows. We first present our stylised network case. We consider investments under a dynamic perspective (including irreversibility of investments and key evolution of congestion on time) and network reinforcement indivisibilities (i.e minimum block of network development because of technical constraints)

We secondly set a framework based on a theoretical "social benevolent planner" who decides network and flexibility investments and manage whole dispatch with the target to minimize to total social-cost. More precisely, the benevolent planner minimizes social-cost over a five-year horizon and have perfect information about the future.[8] This framework allows us to obtain the "first-best" solution, i.e., the optimal arbitrage between network and flexibility development that will be used as the reference to compare with realistic market design options. Moreover, first-best framework is useful to illustrate the impact of key parameters (e.g., network cost considered) on socially optimal network investment strategies and flexibility assets uses, emphasizing their complementarity and substitutability and thus the need of coordinated deployment of these two types of assets.

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[8] For the sake of simplicity we do not represent here uncertainty and risks inherent of network and flexibility investment decisions. The idea is to focus on issues related of sharing of available information. Including uncertainties is one of the possible extensions of this paper, as discussed in the conclusion.

Finally, we analyse the same example but considering different market designs and highlight the possible negative consequences on social-welfare of the uncertainty and lack of commitment created by pure energy market designs.

3.1 Stylized example

To illustrate the arbitrage between flexibility sources and network development we develop a stylized example inspired by Stoft (2006).

The simplified and stylized power system is composed by two areas: distribution and external area. These two areas are connected by a network infrastructure linking the distribution area with the external zone where main generation is located (here represented by an unique asset -“asset E”). The network infrastructure inside the distribution area (“Line A”) has limited capacity. Consumption is concentrated in the distribution area and a flexibility source (F) could be developed inside this constrained area.

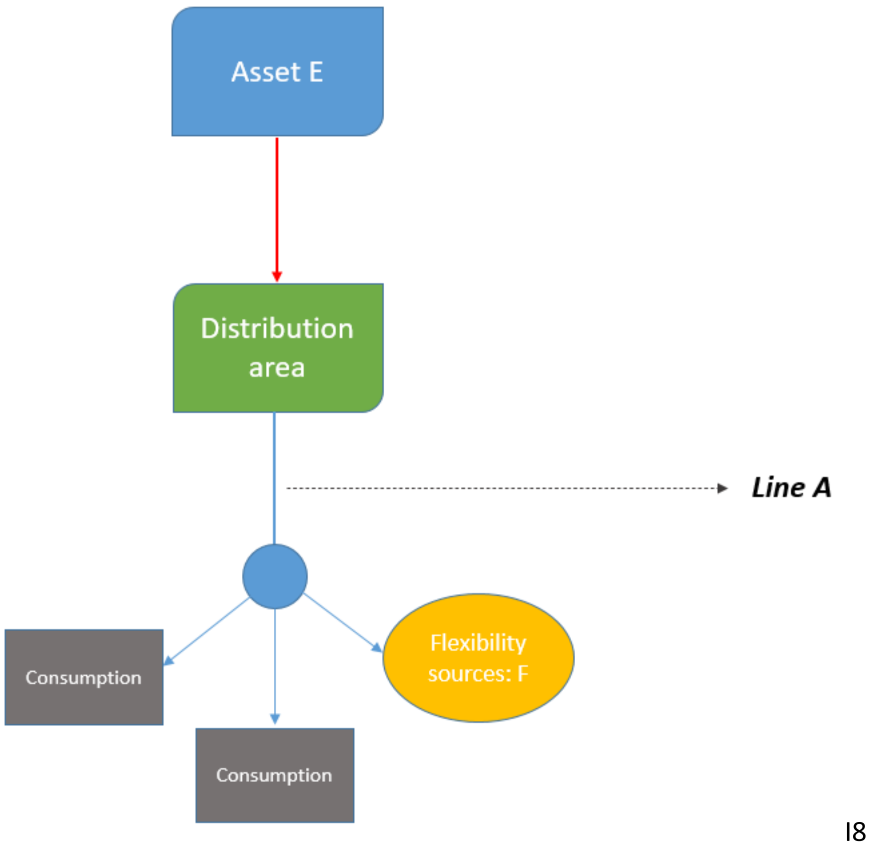

Figure 1: Illustration of our simplified system

3.2 First-best or socially optimal solution

Benevolent social planner will find the optimal solution (called the "first-best") given problem parameters (network investment cost, flexibility investment and use costs, level of consumption, etc). In our case, for the simplicity and the understanding of our example we consider a simplified middle-voltage network, and congestion would be solved by using flexibility (increase of production), load shedding or network development[9].

An optimal solution then means a level of network investment (i.e., the capacity of Line A), a level of investment in the flexibility source (installed capacity of F) as well as the use/dispatch of this flexibility and of the asset E. In this example this coordination will be realise by the Social Benevolent Planner.

We consider that congestion in line A can happen only during peak consumption hours (i.e., when consumption is below peak demand there is no congestion in the area).

Its benevolent planner objective function is to minimize the total cost for the dispatch and investment in flexibility and network with:

$$\sum_{y=1}^{5} CT_y$$

With $CT_y \ = \ \left(P_{e_y} * Cm_e + P_{f_y} * Cm_{fl} + shed_y * VOLL\right) * h_y + CaNet_y * C_r + Iflex * \ CaFle_y$

Constraints for the minimization of social benevolent planner will be:

- $P_e + P_f + shed = LPD$ which represent the energy balance of the system
- CaNet $- P_e \geq \ 0$ because network reinforcement should be made at the level of production of the asset a determined.
- $CaNet_{y+1} \ \geq Capa_y$ representing the irreversibility of network investments
- $CaFle - Pf \geq 0$ the level of use of flexibility (injection) should respect the installed capacity of flexibility.
- $CaFle_{y+1} \ \geq CaFle_y$ representing the irreversibility of flexibility investments
- $P_e \geq 0$
- $P_f \geq 0$
- $shed \geq 0$

The variables considered in our model are:

[9] More generally, congestion-management would refer to several different actions, which would be different depending on network topology, voltage level etc… (Hirth and Glismann, 2018).

- P_e is the level of production of the external asset E (representing the rest of the system)
- P_f is the production of flexibility asset F
- $shed$ is the level of electrical load shedding
- *CaNet* is the level of network capacity chosen (Line A) / discrete variable to represent indivisibility
- $CaFle$ is the level of capacity of flexibility asset developed.

Parameter used in this model and our assumptions are summarized in table 1.

Components	***Definition***
VOLL	Cost of load shedding
Flexibility sources	Cm_f = marginal cost of production of flexibility assets $Iflex$ = annual cost of flexibility assets capacity.
Asset E	Cm_e= Marginal cost of production for asset E
LPD	Local peak demand on the area (fixed).
C_r	Annual cost of network development with considering indivisible block of network reinforcement of 1 MW.
h	Number of hours concerned by peak demand[10]

Table 2: Parameters for optimal congestion-management.

3.2.1 Illustration of first best solution with reference network cost scenario

To develop our example we will take numerical assumptions defined in the table 2.

Components	***Definition***	***Value used in our example***
VOLL	Cost of load shedding	$1000€/MWh$
Flexibility sources	Cm_f = marginal cost of production of flexibility assets	$Cm_f = 300€/MWh$

[10] We consider than when consumption is below peak demand there is no congestion in the area

	$Iflex$ = annual cost of flexibility assets capacity.	$Iflex = 15000€/MW.year,$ [11]
Asset E	Cm_e= Marginal cost of production for asset E	30€/MWh
LPD	Local peak demand on the area (fixed).	1,5 MW
C_r	Annual cost of network development with considering indivisible block of network reinforcement of 1 MW.	*Depending on scenarios.*
h	Number of hours concerned by peak demand[12]	*Defined in Table 3.*

Table 3: numerical assumption for example 1

We realize optimization based of 5 year-horizon, and total cost (CT) will be the sum of the whole time-horizon, with flexibility and network development possible at any year. Based on this example we illustrate optimal strategy of the social benevolent planner considering hours' evolution of local peak demand as defined in table 4. In our illustrative example the number of hours with peak demand significantly increases in year 3 and this mimics potential massive arrival of new usages of electricity (e.g., fast VE chargers or heat pumps).

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Hours of peak demand (h)	20	40	200	200	200
Local consumption during peak hours (MWh)	30	60	300	300	300

Table 4: Number of hours of peak demand and concerned by congestion.

The social benevolent must consider the anticipated evolution of congestion level as well as the cost of network development to decide optimal investments. Here, we illustrate socially optimal strategy considering $C_{r_1} = 35\,000€/$ MW.year as reference scenario. The optimal strategy with C_{r_1} is summarized in table 5.

[11] We consider the cost of generator defined in (RTE, 2017)

[12] We consider than when consumption is below peak demand there is no congestion in the area

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total cost**
Network capacity (MW)	1	1	1	1	1	*325 000€*
Flexibility capacity (MW)	0.5	0.5	0.5	0.5	0.5	
Asset E (MWh)	20	40	190	190	190	
Asset F (MWh)	10	20	95	95	95	

Table 5: Optimal strategy with considering scenario 1 (reference scenario)

To reach first-best social benevolent planner have to develop both flexibility assets and network capacity $(Iflex\ \&\ C_r > 0)$, and used both to realise the optimal dispatch during the five years $(P_e \& P_{f_y} \geq 0)$.

Numerically, to reach first-best social benevolent planner will develop 0.5 MW of flexibility and 1 MW of network capacity in the first year. During the five years, optimal dispatch is characterized by providing 1 MW of the local peak demand with production from asset E, and the remaining level with the flexibility assets. It is important to notice that in this scenario the flexibility assets is used during the five years.

3.2.2 Illustration of first best solution with second scenario of network development cost

To illustrate the impact of network development cost in the strategy of social benevolent planner we develop a second example considering a lower network development cost, $C_{r_2} = 25\ 000$€/ MW.year.

Because network development to fulfil the local peak demand with asset A would appear cheaper, decision of network development would occur for a less amount of congestion considered. Table 4 summarizes differences between both scenarios.

Scenario		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
C_{r_1} = 35 000€/MW.year	*Network capacity (MW)*	1	1	1	1	1
	Flexibility capacity (MW)	0.5	0.5	0.5	0.5	0.5
	Asset E (MWh)	20	40	190	190	190
	Asset F (MWh)	10	20	95	95	95

C_{r2} = 25 000€/MW.year	*Network capacity (MW)*	1	1	2	2	2
	Flexibility capacity (MW)	0.5	0.5	0.5	0.5	0.5
	Asset E (MWh)	20	40	285	285	285
	Asset F (MWh)	10	20	0	0	0

Table 6: optimal strategy with considering different network cost.

In the second scenario, network investments evolve over the horizon. Theoretically, it shows than with this assumptions, flexibility assets would be developed ($Iflex$ & $C_r > 0$), but will not be using after few years.

Numerically, as in the first scenario, 0.5 MW of flexibility asset and 1 MW of network are developed during the first year, but with the evolution of congestion, additional capacity of network (1MW) is developed in the third year. In terms of dispatch, local peak demand would be fulfilled during the first two years using both centralized asset (for 1 MW) and flexibility assets (0.5 MW). But with network development on the third year, the whole dispatch will be realized thanks to centralized asset (1.5 MW), despite than flexibility capacity has already been developed.

3.2.3 Conclusions

The optimal arbitrage between network development and uses of flexibility assets considering indivisibility of network reinforcements and dynamic evolution of congestion level is not easy to determine. It depends of many parameters, and strategy would evolve over the time. For instance, optimal investment strategy depends on the cost of network development. In some cases we observe that flexibility assets would be used only few years before network development.

All this suggests that the need of coordination between network and flexibility development is strong. This is not a problem of for a theoretical social benevolent planner, given that he has all the relevant information and all the decisions are centralized by him.

In a more realistic world it must be more complicated. In a liberalized point of view, coordination between network development by the network operator and flexibility assets investment by unregulated investors will imply a certain level of centralization, commitment and information sharing of each player. This coordination mechanism, which will be presented around a market, should imply different results depending on design chosen. In the next section we analyse this problem.

There is then a need of providing a strong and clear vision of the future needs to develop appropriate level of flexible capacity assets. Information should be shared to be known both by the market participants and DNO (no asymmetry of information), both for year 1 and for the subsequent years.

There is also a need of commitment to ensure that flexibility is developed and used, and not replaced for alternative network development. Otherwise flexibility assets would miss useful development.

This is this kind of risks which will prevent some useful flexibility development (with others network-cost assumption), without clear information sharing and commitment from the network operator.

3.3 Congestion-management in liberalized electricity system using different market-design

Obviously, there is no social benevolent planner in liberalized and unbundled electricity system; in the one hand, congestion management and network development is undertaken by (regulated) network operators and on the other hand, flexibility sources will be developed by market players. Coordination between network reinforcement and the use of local flexibility will be even more complex and will depend on the design of "coordination tool" to express flexibility needs, developing appropriate level of assets, and the commitment from the buyer side.

Local flexibility markets are emerging in Europe as a coordination tool allowing to express DNO needs and gives the information and incentives to private actors to develop flexibility sources to an appropriate level and on specific location. To proceed, market should also provide a robustness and sufficient signal to incentivize efficient actors to realize the investments, with providing a sufficient level of information and ensuring commitment to have a robust vision of the future. All these properties of the local flexibility market depend on its specific market-design.

There is a considerable diversity of local flexibility market-designs (Ramos *et al.*, 2016, Schittekatte and MEEUS, 2019, Esmat et al., 2018b, Dronne et al., 2020). In the following example we illustrate coordination issues with using a simple market-design developed in Esmat et al., (2018b) and in initiatives as ENERA: a separate order-book for localized flexibility offers focus on activation and only energy remuneration. We also illustrate an example with information sharing without commitment from the DNO, and finally perfect information sharing with commitment on several years from the DNO.

Under this market design flexibility players must anticipate local price signals (level and number of hours) to estimate future remuneration and decide to invest or not. Anticipating local price signals will be rather easy if flexibility players have key economic and network information and relevant knowledge to transform them in prices. But in the real world the information on network state, congestion development and network development decisions have not often transparently shared by network operators with market actors. Decision of investment in flexibility assets by market actors have then to be realized with being in a large part blind to the future due to asymmetric information on the possible evolutions, and the lack of commitment from the DNO.

3.3.1 Illustration of the impact of asymmetric information on flexibility investments and on global economic efficiency

To illustrate the impact of the uncertainty due to asymmetric information and lack of commitment we develop the same illustrative example than in section 3.2 but contextualized on an unbundled and liberalized system.

Here we consider that investment decisions are taken on two stages.[13] At the first stage, flexibility providers decide if they develop or not flexibility assets according to the information and the commitment they have. We suppose that actors have all relevant information about the network (cost of asset E, consumption, hours of peak demand, etc.) except the cost network development. They will so develop flexibility sources if they have received the appropriate market incentives or signals to proceed.

Thus, they consider two scenarios to represent the cost of network development (the same scenarios developed in section 3.2). As they do not know which scenario of network development cost is the more realistic, they would expect different incomes depending on their situation (with commitment and information or without).

At the second stage, network operator which knowing that scenario 1 (reference scenario) is the real value of network, decides network investment given flexibility availability. Congestion management will so being managed with arbitrage between network development and flexibility use, only if deregulated investors have received enough incentives to develop those. Otherwise congestion-management will be realized only with network development, which, as highlighted in first section, could be suboptimal to reduce congestion-management cost.

We will use common assumptions with our model developed in section 3.2, with the same network configuration (E & F).

[13] Our example is inspired of Conejo et al., (2016) which develop a dynamic investment model of jointly network and production assets. They develop a bi-level optimization problem, with an upper-level which represents the expected profit maximization of the strategic producer and a lower-level problem representing the market-clearing with the target of maximizing the social welfare.

On first stage flexibility investors have a simplified investment model: Investors considers an income scenario on the next 5 years to decide to invest in a level of capacity of flexibility assets or not in T0. We consider:

Rf	$Flexibility\ remuneration$
$Iflex$	Yearly investment in flexibility
Cm_f	*Marginal cost of production of the flexibility assets*
Y	*Years considered*

Table 7: Assumptions for flexibility development in liberalised context

Flexibility investors will then have to take investment decision based on income expectation, without knowing which scenario (between scenario 1, 2 will occur). Investment on flexibility assets will be based on a simplified assumption: investment will be realized if income is expected to compensate their total cost (Investment and variable cost).

The second stage will represent congestion-management problem with target to minimize social-cost realize by network operators, which knowing the cost of network development (scenario 1). We will analyse congestion-management cost depending on flexibility investors' decision: If investment in flexibility assets have not been realized by unregulated actors, network operator should use network development or load shedding to solve congestion.

Our objective function is still the same:

$$\sum_{y=1}^{5} CT_y$$

With $CT_y = \left(P_{e_y} * Cm_e + P_{f_y} * Cm_{fl} + shed_y * VOLL\right) * h_y + CaNet_y * C_r + Iflex * CaFle_y$

With the constraints explained in the first part:

- If $(Rf_i) < Total\ flexibility\ cost\ , CaFle = 0\ MW.$

We give an illustration for three different market-design:

- 1st : Commitment and perfect information sharing
- 2nd : Information sharing and no Commitment

- 3rd : No commitment and no appropriate information sharing.

In the first situation, market actors have information from the DNO and would anticipate the correct network development cost.

In the second situation, market actors have information on network development cost but no commitment from the DNO.

In the third situation market actors have no information and no commitment from the DNO.

3.3.2 Congestion-management under uncertainty

We taking as numerical assumptions:

Rf	$Flexibility\ remuneration$	$\sum_{y} 500€/MWh^{14} * MWh_y$
$Iflex$	Yearly investment in flexibility	$15000\ €/MW.year$
Cm_f	*Marginal cost of production of the flexibility assets*	$300€/MWh$
Y	*Years considered*	$[1,5]$

Table 8: Numerical assumptions for flexibility development in liberalised context

In the first example with commitment and information investors will anticipate enough remuneration to realize an investment with certainty and confidence. Numerically in this case $R_f = 63\,000€$ $and\ Total\ flexibility\ cost = 37\,500€$. Because $R_f > Total\ cost$, network operators will have the possibility to use flexibility assets to realize congestion-management. For a level of congestion as defined in section 2 we find $CT = 325\,000€$.

In the second time we consider an investor which has information but no commitment from the network operator. In this case market actor will consider the average possible income to define their investment strategy. Because of the lack of commitment and uncertainty, useful flexibility assets will not be developed. Numerically, in this case $R_{f2} = 34\,500€$ and $Total\ flexibility\ cost = 37\,500€$. They would expect a level of remuneration not important enough to realize an investment in flexibility

[14] For simplicity we consider a fixed remuneration for flexibility assets at 500€/MWh

assets. Because $R_f < Total\ flexibility\ cost$, network operators will not have the possibility to use flexibility assets to realize congestion-management. For a level of congestion as defined in section 2, we find $CT = 379\ 000€$

In a third time we consider an investor with no information and no commitment from the DNO. In this context market actor will consider the worst possible income to define their investment strategy. Because of these two market-failures, investment would not be realised. Numerically, in this case $R_{f_3} = 6000€$ and $Total\ flexibility\ cost = 37\ 500€$. In this case also they would expect a level of remuneration not important enough to realize an investment in flexibility assets. Because $R_f <$ $Total\ flexibility\ cost$, network operators will not have the possibility to use flexibility assets to realize congestion-management. For a level of congestion as defined in section 2, we find $CT =$ $379\ 000€$.

In our example commitment and lack of information will cost 54 000€ to social-welfare. Table 7 summarizes the different issues relating to the expectations.

Scenario expectation from investors	*Arbitrage of network operators*	***Year 1***	***Year 2***	***Year 3***	***Year 4***	***Year 5***	***Total cost***
$\boldsymbol{R_{f_1}}$	Network capacity (MW)	1	1	1	1	1	325 000€
	Asset E production (MWh)	20	40	190	190	190	
	Flexibility asset production (MWh)	10	20	95	95	95	
$\boldsymbol{R_{f_2}}$	Network capacity (MW)	2	2	2	2	2	379 000€
	Asset E production (MWh)	30	60	285	285	285	
	Flexibility asset production (MWh)	0	0	0	0	0	
$\boldsymbol{R_{f_3}}$	Network capacity (MW)	2	2	2	2	2	379 000€
	Asset E production (MWh)	30	60	285	285	285	
	Flexibility asset production (MWh)	0	0	0	0	0	

Table 9: Congestion-management cost depending on information in liberalized context

3.3.3 Conclusions

Because of asymmetric information and lack of commitment, investment in flexibility assets would not be realized. In this frame, network operator will not have the possibility to solve congestion with using flexibility assets, and it will generate in some case an increase of social-cost of the dispatch.

Market would be a coordination tool which will enable spread of information, but also which will allow to send signal for appropriate investment. We will observe in the next section lack of market-design described, and possible answer to solve investment issue.

4 Discussion: which alternative market design to address uncertainty and provide appropriate incentives to develop local flexibility assets?

In section 2, we have introduced the specific consideration of investment in local flexibility assets in the light of institutional economics and highlight these requirements.

In section 3 we have developed an analytical demonstration of these requirements with the first best (socially optimal solution) for the arbitrage between network and flexibility uses. We have highlighted the optimal arbitrage between network and flexibility development and then the possible problematics with a local flexibility market focus on energy. We have particularly identified two factors which could lead to a high uncertainty, asymmetric information and lack of commitment from DNO.

To ensure appropriate level of investment, market-design should reduce these uncertainties. In this section, we first identify a main problematic of a local flexibility market on the frame expressed before, with short-term management and remuneration to energy, to provide enough incentives for investment. Then, we discuss a potential alternative market-design based on multi-year (long term) capacity contracts.

4.1 Local long-term capacity auction

Long-term capacity auction will provide answers to problems described in last section.

According to institutional economics, to solve asymmetric information's problematic and possible adverse selection, contractual elements must be developed (Williamson, 1985). Long-term capacity auction will provide greater visibility and information on the strategy for strengthening the network over several years.

Long-term capacity auction will give visibility on the willingness to pay for flexibility services over several years, reveal the value of flexible capacity from network operators (Neuhoff and De Vries, 2004, D. M. Newbery 2003). Local capacity auction would also reveal cost structure, especially regarding to the cost of network reinforcement and allow a better anticipation from the investors (Laffont and Tirole, 1988).

It also implies commitment from Distribution Network Operator and then reduce moral hazards. As expressed by (Williamson, 1985) *"the commitment of specific assets to a contract by one party leads to exit costs which generate hazards of expropriation".* Solving risk of moral hazard would then imply warranties and certainties (Emons, 1988). With fixed amount of capacity reservation on several years, risk of value disappearance is considerably reduced. Long-term auction will flattens the opportunism of the grid operator to withdraw payments he has signalled to a distributed generation's investor after the undertaken investment (Vogel 2009), and then reduce the possibility of "adverse-selection" for the market actors. With defining a fixed capacity remuneration realized by network operator it will also allow investors to reduce the exposure of a volatile short-term market price or demand-side evolution (Deng and Oren 2006, Moreno et al. 2010, Neuhoff and De Vries, 2004). It would then reduce risk-aversion from investors and lead to an increase of social-welfare by allowing appropriate and social-optimizing investment thanks to a better information for investors than with energy-only market-design (Roques and Finon 2017, Neuhoff and De Vries, 2004,de Maere d'Aertrycke et al., 2017).

In terms of implementation, several options are possible. Long-term capacity auction would be realized directly by network operators. If network operators have not directly the right to develop the assets themselves according to Clean Energy Package[15], they have the right to sign long-term commitment with actors if they follow competition principles. It is for example the case in UKPN flexibility market, where long-term contract should be sign until 7 years (UKPN, 2020). To organize the auction, a mechanism "price-based", where the amount of the procured capacity is steered by setting a target price seems adapted to an arbitrage between network development and flexibility uses as we have described in our furthers sections (European Commission, 2016). To allow new possible entrants and ensuring a competition as strong as possible it is then possible to deploy local forward auction for

[15] Except some particular cases

capacity with short-term market for energy (Oren, 2003). These auctions should be realized by network operators, combined with activation energy market to ensure competition as much as possible.

4.2 Regulation evolution

Reducing risk and mainly from the informational aspect may also come from regulation evolutions. To answer to the fear of adverse selection, as explained in (Sappington, 1991) network's operator should communicate some keys data and information before contracting to avoid pre-contractual information asymmetry. (CEER, 2020) has also notify the willingness to realize DNO network development plans, as the image of what it made on transport level.

To allow a better visibility on distribution network operator's strategy, there is a need of Equal approach for CAPEX and OPEX for network development: Currently, network development choice can also be hard to predict for investors because network development decisions deviate from the optimum because network operators have incentives to realize network development (CAPEX) rather than using alternative solutions as flexibility (OPEX) (Brunekreeft and Rammerstorfer, 2020).

5 Conclusion

Using flexibility assets to solve congestion on distribution network with development of decentralized resources and increase needs of congestion-management at the distribution level is gaining more and more interest. But the coordination need to ensure the social-efficient arbitrage between network development and flexibility use is significant, especially when one consider dynamic perspective and other real-world features as indivisibility of network development and evolution of congestion level.

In a liberalized and unbundled world, the coordination between network investment and investment in flexibility from unregulated actors is even harder to realize. Indeed, asymmetric information between network operator and investors, and lack of commitment from network operators considering a local flexibility market based on short term energy remuneration does impact flexibility development, and lead to over-cost to solve congestion than the social-optimal level.

An appropriate market-design should answer to these problematics, but activation market-design of local flexibility market with energy only remuneration would not reveal many information about willingness of network operators and not provide commitment. It is then interesting to provide long-term vision and to reduce market risk to ensure an appropriate level of investment.

We discuss the possibility to add one element to this market-design to solve problems identified: Local long-term capacity auction. Long-term capacity auction will reduce market-risk, with revealing information about the value of flexible capacity for network operator, but also their willingness over the time and their cost structure. It will also provide commitment and reduce moral hazard, to cover risk of activation market-based revenue with possible strategy evolution. Long-term capacity auction should be realized by network operator, combining with activation energy market to ensure competition as much as possible.

Regulative evolution to ensure a better diffusion of key information from network operator, but also a better anticipation of their strategy would also be useful.

If the analysis we have proposed allow to characterize the risk of asymmetric information and lack of commitment for investment in flexibility assets based on market focused on activation, those risk have to be better quantify and model in the future. They should of course be implemented in a more general frame for flexibility remuneration, with considering the possibility for flexibility to multi-market competition but also consider the others possible sources of risk and modelized different DNO regulation. The other way to mobilize flexibility on distribution level must be considered. Finally, the appropriate uses of flexibility and coordination between local and national level have still also to be defined.

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