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Pipeline Flexibility in Liberalized Gas Markets**

by

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Gas Balancing Rules Must Take into account the Trade-off between Offering Pipeline Transport and Pipeline Flexibility in Liberalized Gas Markets

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Abstract

This paper analyses the value and cost of line-pack flexibility in liberalized gas markets through the examination of the techno-economic characteristics of gas transport pipelines and the trade-offs between the different ways to use the infrastructure: transport and flexibility. Line-pack flexibility is becoming increasingly important as a tool to balance gas supply and demand over different periods. In the European liberalized market context, a monopolist unbundled network operator offers regulated transport services and flexibility (balancing) services according to the network code and the balancing rules. Therefore, gas policy makers should understand the role and consequences of line-pack regulation. The analysis shows that the line-pack flexibility service has an important economic value for the shippers and the TSO. Furthermore, the analysis identifies distorting effects in the gas market due to inadequate regulation of line-pack flexibility: by disregarding the fixed cost of the flexibility in the balancing rules, the overall efficiency of the gas system is decreased. Because a full market based approach to line-pack pricing is unlikely, a framework is presented to calculate a cost reflective price for pipeline flexibility based on the trade-offs and opportunity costs between the right to use the line-pack flexibility and the provision of transport services.

Keywords: gas flexibility – gas balancing rules – EU gas market

1. Introduction

Gas pipelines and compressors are the physical backbone of a natural gas market, and they can be used to make gas flow and to store it. There are, however, important trade-offs between these two possibilities to engage the gas infrastructure. If this dual functionality, which is embodied by line-pack flexibility, is neglected, negative effects are carried into the gas commodity and the gas transport market. Yet, almost no reference to the problems with line-pack flexibility can be found in the literature. The problem is further complicated because aspects of investments, network operations and balancing markets have to be dealt with simultaneously. Therefore, this paper aims to shed some light on the problem setting, and to clarify the economic consequences of the trade-offs between the transport function and the flexibility function of the pipelines in a context of a liberalized gas market.

The pipeline flexibility can be seen as a positive externality of the transport network design, on the one hand; the right to use this flexibility decreases the available transport capacity, on the other hand. So, the benefit of flexibility in the timing of injections and withdrawals that is possible because of line-pack flexibility should be weighed against the harm of reducing available transport capacity in order to assure the flexibility (Coase, 1960). In section 2, we explain in detail the technical relationship between the two functions of the infrastructure. It is evident that the line-pack flexibility has an economic value (for different actors), and that this value can be bigger than the harm provoked by its use. Still according to Coase (1960, p. 7):

“It is necessary to know whether the damaging business is liable or not for damage caused since without the establishment of this initial delimitation of rights there can be no marked transactions to transfer and recombine them.”

In Europe, the right to use the transport flexibility is usually defined by the balancing rules or the network code, as underlined by the European Regulator’s Group for Electricity and Gas (ERGEG, 2009). The Coase theorem further specifies that the allocation of rights has no welfare implications if there is a workable market and price signals. However, in the European gas transport case, the transport function and the network flexibility are considered the monopoly of the network operators, and the related services are considered regulated services with regulated tariffs. Nevertheless, the problem of the dual function has been raised many times by institutions such as the European Commission’s DG Transport and Energy (2005), ERGEG (2006; 2009), and Gas Transport Europe (GTE, 2009). Some national network operators, e.g. GRTgaz in France, have also been concerned about the issue (CRE, 2009a; GRTgaz, 2009). GRTgaz particularly called attention to the problem of whether investments caused by unbalanced shippers, who are the users of transport services, should affect the gas transport tariff of all shippers. As will be shown in sections 2 and 3, line-pack flexibility and balancing are closely related. Keyaerts et al. (2008) and Lapuerta (2003) have shown the possible negative impact of balancing tariffs on the gas market competition, and how these balancing mechanisms potentially increase entry barriers for small shippers. Moreover, many policymakers have advocated that the balancing tariffs should reflect costs and that the offering of a regulated monopoly service should not be a profitable business for a network operator (OFGEM, 2003).

The cost of line-pack flexibility, which is a main tool for balancing operations, should not only reflect the commodity price, but also the infrastructure costs, such as the use of the pipeline and the compressors. The cost decomposition of pipelines between its two functions of transport and flexibility is complex. The supply function of pipeline storage and pipeline transport can be classified by the classic microeconomics theory as a multi-product monopoly with the demand for each product independent (as both have different substitutes) but the costs dependent (Tirole, 1988). Moreover, in Europe gas transport is a regulated monopoly, whereas the pipeline flexibility is competing with other sources of flexibility such as contract flexibility and other storage mechanisms (IEA, 2002). Because of this complexity, the understanding of the trade-offs between the transport function and the storage function of the infrastructure is important. The proper understanding of this allows the opportunity costs of time flexibility to be determined in a similar way as has been done by Lapuerta and Moselle (2002) for an analogous problem regarding geographical flexibility. These authors use the opportunity costs to compare different capacity systems with regard to flexibility rights and tariffs, and to evaluate the market consequences. Opportunity costs have also been applied to evaluate the externalities of energy markets (Oren and Sioshansi, 2004; Pineau and Lefebvre, 2009; Rious et al., 2008a; Rious et al., 2008b).

The definition of costs is essential to determining an efficient tariff because in the absence of a clear market price, it is the tariff rules that define the allocation of rights to use the monopoly infrastructure, addressing the Coase problem as a feasible second best (Glachant, 2002; Glachant and Perez, 2007).

So, this paper aims to contribute to the discussion about the network tariffs exploring the economic consequences of the trade-offs between the gas pipeline transport capacity and pipeline storage. Furthermore, a framework based on the defined opportunity costs is proposed to solve the non-trivial problem of pricing line-pack flexibility. Indeed, in an unbundled market, the bundling of the two very different services of the pipelines is challengeable, and a separate price for line-pack flexibility can increase transparency and efficiency in the market. In order to present this contribution, the next section explains the origins of line-pack flexibility and its uses. In section 3, the economic value and costs of line-pack flexibility are explored for the TSO and the shippers. The consequences of ‘imbalanced’ gas balancing rules and tariffs on the regulated and the competitive parts of the gas market are discussed in section 4. Finally, section 5 presents the main conclusions and puts forward recommendations for gas market policy.

2. Line-pack Flexibility: Origin and Uses

The ability of gas networks to store natural gas inside its pipelines is a consequence of the physical properties of the transport network where the volume gas flow can vary according to the pressure differential as explained in the technical literature (e.g. Eberhard and Hüning, 1990). The transport operator can decide how much gas to transport and how much gas to store taking into account some technical limits. These technical limits determine the line-pack flexibility. We clearly distinguish between the concepts of “line-pack”, which is the total volume of gas present in a pipeline section, and “line-pack flexibility”, which is the amount of gas that can be managed flexibly by controlling the operation pressure levels between a minimal and a maximal level (Fig. 1). The following sections explain how this flexibility is produced in the network as a consequence of the gas transport dynamics, and how this flexibility is useful for managing a gas network system.

2.1. Production of Line-pack Flexibility

The dynamics of gas transport are described by Eq. 1 in which Q stands for the volumetric¹ flow rate (m^3/s), D represents the diameter (m) of the pipeline section of length L (m), and p_{in} and p_{out} are the pressure (Pa) at the inlet of the pipeline and at the outlet of the pipeline, respectively. The constant c represents material and gas characteristics such as pipeline roughness and gas density, and is also dependent on the units chosen for the other parameters.

$$\dot{Q} = cD^{2.5} \sqrt{\frac{p_{in}^2 - p_{out}^2}{L}} \quad (1)$$

$$V_{L\text{Flex}} = w \left(\frac{p_m}{K_m} - \frac{p_{m'}}{K_{m'}} \right) \quad (2)$$

$$p_m = \frac{2}{3} \left(\frac{p_1^3 - p_2^3}{p_1^2 - p_2^2} \right) \quad (3)$$

Basically, the gas flow rate is related to the difference of the quadratic pressures at both ends of the pipeline section, and not the absolute levels of the pressures. Pipelines can be operated at a range of pressures that are limited at the upper bound by a maximal operating pressure (p_{emax}), which is determined by the material characteristics and at the lower bound by a minimal operating pressure (p_{dmin}). This lower bound is the pressure that ensures flow by compensating friction or it can be determined by contractual arrangements for a certain delivery pressure.

The system operator can ensure the safe operation of the pipeline network by operating within a pressure band defined by the maximal and the minimal pressures. This operational flexibility in gas transport networks results in the ability to store gas in the pipelines by using line-pack flexibility,

¹ Volumetric flow rate (Q) under reference standard conditions ($T = 288$ and $p = 101325$ Pa) is equivalent with mass flow rate (m), differing only by a constant reference density

while ensuring the normal gas transport. Both the pressure drop (p_1p_2 or $p_1'p_2'$) required for the transportation service and the available storage potential (area $p_1p_2p_2'p_1'$) are illustrated in Fig. 1.

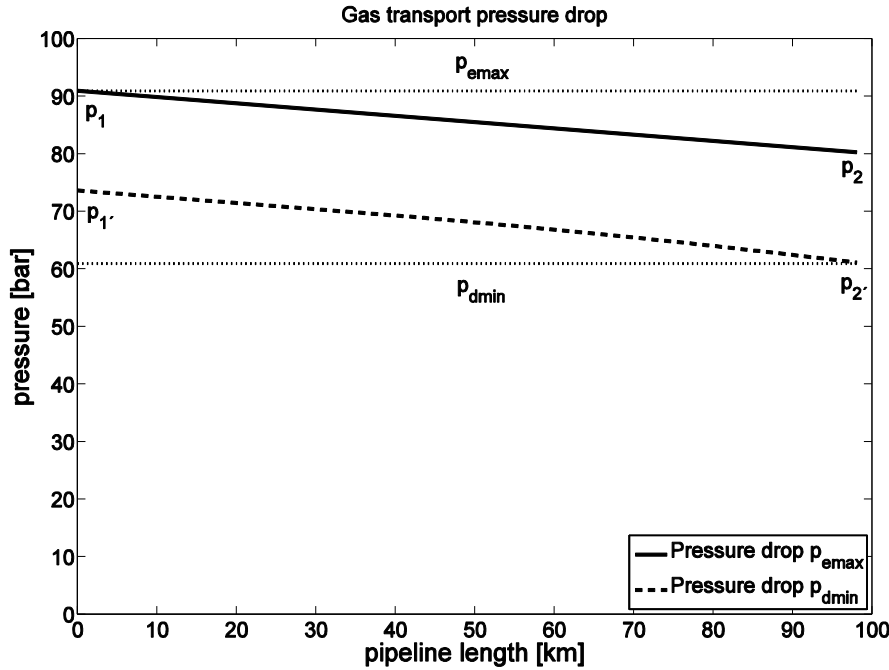


Figure 1: Line-pack flexibility: the area defined by $p_1p_2p_2'p_1'$ represents the storage potential in the pipeline while simultaneously ensuring the transport corresponding to the pressure differential $p_1^2 - p_2^2$ at the lower boundary.

The available line-pack flexibility, expressed in standard cubic meters, is determined by Eq. 2 in which w is a constant that is dependent on the geometric volume of the pipeline and the chosen reference conditions. Basically, the storage potential is dependent on the difference between the higher average pressure p_m (Pa) and the lower average pressure p_m' , which are calculated according to Eq. 3. K_m and K_m' are the compressibility numbers (dimensionless) corresponding to p_m and p_m' , respectively. The lower average pressure depends on the entry pressure and the delivery pressure that correspond to the desired transport flow. If the full pressure differential is required to make the gas flow, there remains no storage potential, whereas if there is no flow the full geometric volume of the pipe can be used to store compressed gas.

2.2. Use of Line-pack Flexibility: Pipeline Storage

Line-pack flexibility is produced by exerting the still available pressure difference and results in the storage of gas inside the pipeline. The basic principle of storage is that one can only withdraw what has been injected before. Therefore, line-pack flexibility operates like a buffer that is filled first, and emptied at a later time. This buffer concept has been defined by Lapuerta as the part of the line-packing, meaning the total volume of gas in the pipeline, that can be used without any safety problem (Lapuerta, 2003, p. 66): “at any point in time, the available buffer is the difference between line-pack at that time and the minimum safe level of line-pack”. In other words, “the available buffer is the maximum amount that line-pack can fall within-day from its current level without introducing a positive probability of supply failure”.

In the framework of this paper, the line-pack buffer at any time is equivalent to the used line-pack flexibility. In the remainder of this paper the concept of *line-pack flexibility* refers to the availability of flexibility and the “service”; whereas *line-pack buffer* refers to the actual use of the flexibility service.

Line-pack flexibility and the gas transport service are interdependent services of which the pipeline flexibility accommodates a different time pattern for the matching of gas injections and withdrawals, as is illustrated by the example in Table 1 in section 3. To allow the withdrawal of gas before the injected gas has reached the withdrawal point, the line-pack buffer has to be used to satisfy demand. This buffer needs to be created and kept in storage within the physical boundaries of the pipeline, and so part of the capacity cannot be allocated to transport services. And the same logic can be applied in the other sense, if the gas is injected in the pipeline by a shipper before a withdrawal demand arises, and the flexibility is guaranteed, it is necessary to keep gas inside the pipeline until there is a demand for withdrawal by that shipper. It cannot be used by a second shipper, unless there is a guarantee that gas will be available for delivery to the first shipper when she demands it. Based on these technical relations one expects trade-offs to occur between offering line-pack flexibility and selling transport capacity.

2.3. *Managing a Set of Pipelines: Balancing*

So, the line-pack flexibility enables the network operator to store gas inside the pipelines to facilitate the matching of gas supply and demand over time. The line-pack flexibility is particularly suited to immediately accommodate short lived imbalances between demand and supply. This subsection briefly discusses gas network balancing in order to facilitate the understanding of some of the economic issues that are dealt with in the subsequent sections about balancing.

Physically, an imbalance occurs whenever the amount of gas injected in the system (m_{in}) is not equal to the gas taken from the system (m_{out}), disregarding losses such as gas consumption in compressors along the pipeline. The correct equation reads:

$$\dot{m}_m - \dot{m}_{out} = \frac{\partial(\rho V)_{storage}}{\partial t} \quad (4)$$

The right hand side term in Eq. 4 reflects the change over time of the gas mass stored inside the pipeline by means of line-pack flexibility. The imbalance is then reflected in that storage term, in which V represents the geometrical volume (m^3) of the pipeline section and ρ the gas density (kg/m^3). Therefore, line-pack flexibility makes balancing gas networks an intertemporal problem because the short term storage in pipelines allows matching demand and supply over a time interval, rather than instantaneously. Although the system operator is ultimately responsible for the safe operation of the network, the shippers should balance their gas injections and withdrawals themselves.

2.4. *Conclusion on the Technical Aspects of Line-pack Flexibility*

Technically, line-pack flexibility is available in any pipeline with a non-flat transport demand profile. To use the pipeline flexibility, the line-pack buffer has to be produced first, though. This buffer is basically just local pipeline storage, which is very useful to manage a gas network. However, as the flexibility needs to be produced and can be applied for different uses there are real economic values and costs involved, which are further discussed in the next sections.

3. Economic Value and Costs of Line-pack Flexibility: Trade-offs

Joskow (2007) argues that the creation of well functioning liberalized gas markets is technically not much of a challenge because of the ability to store gas along the supply chain. However, we argue that the presence of flexibility makes the economics of the gas market liberalization very challenging. Line-pack flexibility in particular is a service with special characteristics that cannot be discussed without taking notice of the whole gas transport system.

In the absence of an efficient market, regulated tariffs reflecting long term marginal costs are a second best solution for the gas transport system as described by Kahn (1971) and Spulber (1989). In Europe, this has resulted in line-pack flexibility being regulated by the balancing rules, which according to EU rules (European Union, 2009a, b) should provide appropriate balancing incentives

to shippers. Furthermore, these rules stipulate that tariffs shall be cost reflective. However, these costs are difficult to determine because they are mixed with the costs of transport. In order to figure out the costs of line-pack flexibility, the trade-offs between line-pack flexibility and transport services need to be examined and the related opportunity costs can then be used as cost estimates.

3.1. The Economic Value of Line-pack Flexibility

The fundamental value of line-pack flexibility can be attributed to its buffer function to quickly cover temporal imbalances between supply and demand as discussed in section 2. Technically, pipeline storage reflects physical ‘imbalances’. Therefore, the economic definition of a gas imbalance depends on the balancing period, which is the time interval over which nominated gas injections and withdrawals should match and this interval can theoretically last from a second to an hour or even a day or a month. Taking into account that the value of gas demand varies in time, and that the production or import of gas is often less costly when it is flat, there is a value to facilitate the matching of gas demand and gas supply over time.

Moreover, the economic value created by the flexibility to store gas inside the pipeline and to transport gas through a full or empty pipeline can be appropriated by different players: the system operator can use this property to minimize its pipeline investments, whereas shippers can use it for price arbitrage and load management.

3.1.1. Line-pack Value for a System Operator: Network Investment

The system operator is responsible for the network investment and thus for the dimensioning of the network. Therefore, an efficient TSO maximizes the sale of transport capacity while minimizing the capacity that it builds. Line-pack flexibility helps the TSO to avoid over-investment, meaning an investment in capacity that will not be used during the pipeline depreciation horizon.

In a network based on entry/exit schemes, transport capacity is marketed through the separate selling of entry capacity and exit capacity, as detailed by Lapuerta and Moselle (2002) and KEMA (2009). Table 1 provides a basic example of entry flows (supply) and exit flows (demand) for two periods Δt_1 and Δt_2 , each lasting one hour. The demand varies between 400 (m³/h, fictional numbers) in the first period and 600 in the second period. For the supply there are two options. Option 1 exists in supplying exactly the demanded flows in each period, whereas option 2 takes into account the available line-pack flexibility and supplies 500 in every period.

The exit capacity offered by the system operator should allow the delivery of gas during the peak period. Therefore the exit capacity needs to amount to 600. The system operator can now choose the amount of entry capacity it offers to the gas suppliers. The straightforward solution is to allow the suppliers to follow the demand with the supply flows and offer a capacity of 600 at the entry as well. In that scenario the upstream pipeline infrastructure needs to be designed to deliver 600 at the entry point in period 2 (either by pipeline flow or storage).

Table 1: Example of demand and supply flows for two hourly periods (Δt_1 and Δt_2) under different capacity offers, injection before withdrawal (author elaboration)

m ³ /h	Demand	Supply option 1	Supply option 2
	Exit cap 600	Entry cap 600	Entry cap 500
Δt_1	400	400	500
Δt_2	600	600	500

If the system operator takes into account the presence of line-pack flexibility, on the other hand, it invests in an entry capacity of 500 that is fully used in both periods. Moreover, this solution allows optimizing the investment in the upstream infrastructure to deliver a stable flow of 500 in the two periods instead of building a transport capacity to handle the production/import peak of 600.

3.1.2. Line-pack Value for a Shipper: Load Management and Price Arbitrage

In a liberalized gas market, the shippers, who can be any gas buyer or seller, are profit maximizing market players. They buy their gas as cheap as possible and sell it as expensive as possible (or use it when it has a bigger economic value). This means that in a market context shippers prefer to buy gas on a flat-rate basis, avoiding additional costs associated with volatile production, or when prices are lower due to lower demand in that period. The gas is then preferably sold in peak periods, which have higher prices (IEA, 2002).

So, if an opportunity turns up for a shipper to buy cheap gas in Δt_1 , inject it in the pipeline and sell it at a premium in Δt_2 , the shipper will be interested in using the line-pack flexibility to arbitrate between prices. Evidently, a shipper could also sell the gas from the line-pack buffer in Δt_1 , if the gas has a high price, and inject it into Δt_2 , when the gas has lower prices to match his purchase and sales portfolio.

Looking at example 2 (Table 2), which is similar to example 1 except that the peak demand is now in period 1 and the off-peak demand in period 2, there are two options for the supply side. Option 1 exists in supplying exactly the demanded flow in each period, whereas option 2 uses the line-pack flexibility to cover the difference.

Table 2: Example of demand and supply flows for two hourly periods (Δt_1 and Δt_2) under different capacity offers, withdrawal before injection (author elaboration)

m ³ /h	Demand	Supply option 1	Supply option 2
	Exit cap 600	Entry cap 600	Entry cap 500
Δt_1	600	600	500
Δt_2	400	400	500

Again, the exit capacity offered by the system operator should allow the delivery of gas during the peak period. Therefore, the exit capacity needs to amount to 600 (m³/h). The system operator cannot be sure that the gas will be completely injected in Δt_1 because the shipper has the flexibility to inject only 400 or 500 and still take-off 600. To deal with this situation the system operator needs to have gas in pipeline storage from period Δt_{t-1} to allow the withdrawal of 600 before the shipper makes the matching injections. The TSO, as the safeguard of the gas system integrity, needs to anticipate this withdrawal and keep gas in pipeline storage (Lapuerta, 2003). This flexibility has a cost. These institutional aspects are further developed in section 4.

3.2. The Costs of Line-pack Flexibility for the TSO

The fixed cost of line-pack flexibility for the TSO can be evaluated by the part of the pipeline cost used to store gas in order to address unbalanced situations, or by the opportunity cost of the line-pack flexibility, which is the market value of the available transport capacity with and without line-pack flexibility. The examples from the previous section illustrate this argument: to sell the firm withdrawal capacity of 600 m³/h, the TSO needs to ensure that the pressure level in the pipeline will not drop below the pressure level required for the load buffer, meaning that the pipeline company needs to keep the gas in storage that might be withdrawn before the matching injection is made. Looking again at the example in Table 2, the cost of line-pack flexibility is thus equivalent to the price of 100 m³/h transport capacity that cannot be used in preceding period Δt_{t-1} in order to build up the buffer to guarantee the safe flexible operation of the network according to supply option 2.

In the vertically integrated gas industry the costs of flexibility were inserted in the integrated company's pool of costs to supply gas to consumers. In the unbundled European gas industry the picture is very different. Today, the transport network is managed by a separate system operator which is responsible for the execution of the transport service and the system balancing, which is physically dependent on the pressure management as explained in section 2. Because of its obvious relationship with the pressure management of the pipeline system, line-pack flexibility in Europe is controlled by the system operator. So, the basic short term trade-off for the system operator exists

in the mutually exclusiveness of offering a unit of the pipeline storage service versus offering a unit of the pipeline transport service within the framework of a physically limited pipeline capacity. This trade-off implicitly defines the line-pack cost for the TSO.

The suppliers (shippers), on the other hand, hand over gas to the system operator at entry points and take back control over the gas at exit or delivery points. They actually cause imbalances if their injections do not match their withdrawals. *“In a liberalised market, system balancing is achieved through the interaction of networks users and the TSO. Whilst network users should aim to minimize and be obliged to take the financial responsibility for any deviation between the inputs and off-takes, the TSO remains the only instance that is able to ensure the physical balance of the overall network”* (KEMA, 2009, p. 34). Therefore, the system operators in Europe have installed balancing mechanisms in order to transfer the costs of imbalances to the shippers who have caused the imbalances and to incentivize the shippers to balance their flows *ex ante* by means of storage and other flexibility contracts on the market.

3.3. The Cost Allocation of Line-pack Flexibility: The Balancing Mechanism

In Europe the line-pack costs are usually socialized by means of the transport tariffs and in part allocated to shippers through the balancing rules, charges and tariffs.

A typical balancing mechanism specifies time and space boundaries in which the shipper has to balance. Furthermore, the balancing mechanism specifies imbalance charges that should reflect the costs incurred by the system operator to balance the transport system. In actual EU balancing regimes, however, line-pack costs are not included in an efficient way as the allocation of line-pack costs is dependent on the balancing period, the tolerance levels, and the way balancing prices are determined (ERGEG, 2007; KEMA, 2009).

3.3.1 Balancing Mechanism Definitions

First, the definition of the balancing period, which is the time interval over which to balance gas injection and withdrawal, is a key issue because this definition determines how long the network is obliged to guarantee free storage to shippers. If the balancing period is an hour, the shippers need to balance injections and withdrawals every hour; whereas in a daily balancing mechanism the shippers should only balance every 24 hours. Inside the balancing interval, the operator should balance the system at no cost for the shippers. Therefore, and referring to the examples in Tables 1 and 2, the system operator needs to provide gas from (pipeline) storage in case a shipper withdraws gas before he injects, and needs to keep gas in storage that was injected for withdrawal at a later time.

Imbalances within the balancing period have no financial consequences for the unbalanced shipper. In other words, flexibility costs within the balancing period are socialized. Some countries, however, have added rules to limit the free flexibility inside the balancing period (e.g. hourly limits in a daily balancing system). These rules are meant to discourage huge differences between injections and withdrawals over smaller periods.

Second, the definition of the imbalances that are subject to balancing charges and the size of these charges is not homogenous in Europe. Balancing rules have very different approaches to dealing with tolerance levels and penalty charges. For instance, in some balancing mechanisms there are different prices according to the size of the imbalance. Imbalances below a certain level are charged a price P_{ref} or even no price at all, whereas larger imbalances are considered excessive and are subject to a price P_{ref} plus a penalty x . The small imbalance that is less expensive or free is defined by the tolerance levels. The balancing interval and the tolerances actually are reflected in the availability of line-pack flexibility. By offering tolerances the system operator commits to keeping a certain level of line-pack flexibility for storage services at the cost of selling this capacity for the purpose of transport. In systems that have a smaller balancing interval or do not offer tolerances,

the system operator can sell more capacity for transport services. Therefore, the cost of different balancing rules can be calculated based on the opportunity cost of pipeline transport capacity.

Third, different systems exist to set up a price structure for balancing charges. The Italian balancing charges are based on the tariffs for underground storage, but most European balancing mechanisms base the balancing charges solely on gas prices, as is recommended by ERGEG (2009). In other words, by the end of the balancing period a shipper should not have any remaining imbalances. If the shipper has imbalances, he will be subject to pay the cost for the equivalent amount of gas as if that gas had been bought or sold on the market².

An illustration of a daily balancing mechanism with additional within-day rules and tolerances is provided in Fig. 2. A basic daily balancing mechanism only cashes out the end-of-day imbalance, which is the last point of the full line. The bars represent the free intra-day flexibility for the shipper. The addition of within-day penalties for excessive, meaning beyond the tolerated levels (dashed lines), hourly imbalances and for the peak cumulative imbalance over the day, implies that within-day flexibility is no longer costless for the shipper.

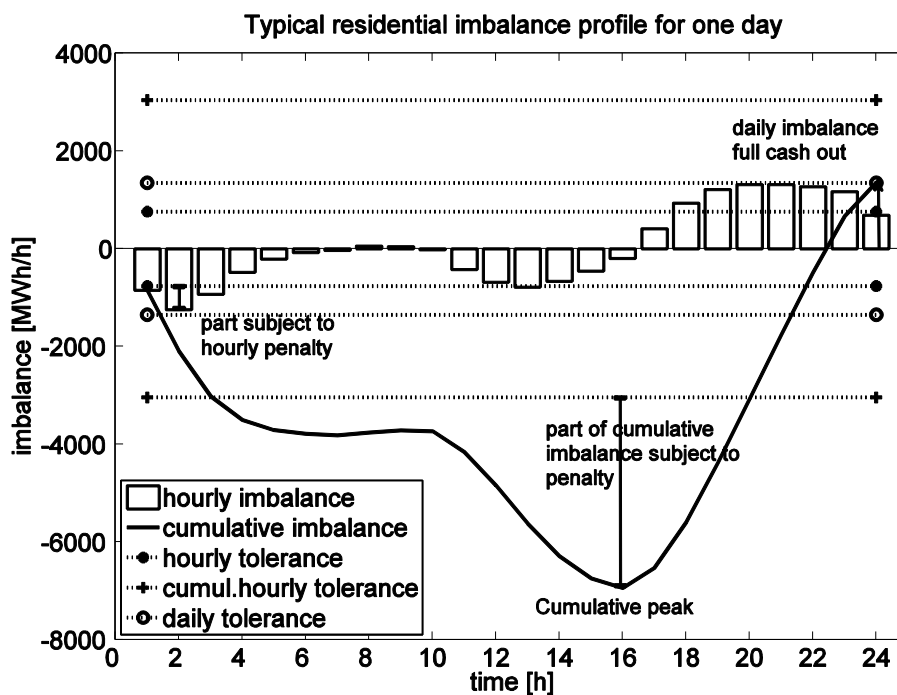


Figure 2: Illustration of a daily balancing mechanism with additional within-day charges and tolerances

Taking into account the above definitions, balancing mechanisms can be further divided in regulated and market based mechanisms. Although the EU regulated tariffs should reflect the balancing costs of the system, these tariffs do not include, at least not in a public and transparent manner, the physical costs of the network. On the contrary, the charges are mostly based on gas prices and often appear to be solely designed to steer shipper behavior. On the other hand, balancing charges that are entirely based on gas market prices actually imply the impossibility to use line-pack flexibility as a tool to store gas. Indeed, such balancing charges come down to an obligation for the shipper to have bought or sold all the gas in the pipeline at the gas price of the period, whereas price arbitrage has the objective of trading gas at different prices in different periods.

² The availability of an adequate market price for gas is an issue that has been discussed by ERGEG (2006; 2009). In this paper, a proper gas price is assumed to be present to show that even in that case line-pack flexibility is treated inadequately.

3.3.2 Balancing Mechanism: European Practice

The majority of EU 15 countries³ formally apply a balancing period of one day, even if the effective balancing frequency is higher due to the imposition of penalties for imbalances over shorter intervals. Such penalties are applied at an hourly frequency in Belgium, the Netherlands⁴, Luxembourg and Germany, or for peak cumulative deviations over the balancing period (Belgium, the Netherlands and Luxembourg), as is illustrated in Table 3.

Table 3: Use of cash out charges and penalties for different balancing frequencies in 15 EU countries (author elaboration, data from KEMA, 2009)

	Penalty (outside tolerance)	Cash out (outside tolerance)	Full cash out
Evergreen	ES, IT, PT	FR	
Monthly			GR
Daily		FR, GR	BE, DE, DK, UK, IE, LU, NL, SE
Cumulative (within-day)	BE, LU, NL		
Hourly	BE, DE, LU, NL		AT

Cash out: payments between TSO and shipper which financially return the imbalance to zero.

Penalty: payment made by the shipper to the TSO when tolerance restrictions are violated

Evergreen: all imbalances are settled in kind

The determination of balancing charges, i.e. cash out charges and penalties, also varies largely between the EU countries (Table 4). However, market based mechanisms play only a minor role in the short term procurement of balancing gas. Non-market based methods continue to represent the main, and often even the exclusive form of procurement in most countries. Moreover, even when market based methods are used, they are mostly based on medium term horizon products.

Table 4: Determination of Cash-out Prices and Penalty Charges in 15 EU Countries (author elaboration, data from KEMA, 2009)

	Administrated	Indexed	Market based	
			Average cost	Marginal cost
1 Price	IT	IE, NL	AT, UK, FR, SE	
2 Price	ES, GR	BE, DE, DK, FR, LU		UK, SE
Penalties and other charges	GR	AT, BE, NL, PT		

Table 5 lists some examples of balancing services that have been proposed by system operators to shippers in order for the latter to accommodate their balancing needs. These services can be a way for the TSO to sell line-pack flexibility and other flexibility tools, unbundled from the transport service. The unbundling allows the costs between shippers to be allocated in a more correct way.

Table 5: New Services of Balancing Offered by TSOs (AT, BE, DE, NL) (author elaboration, data from Lapuerta, 2003 and IEA, 2002)

Available flexibility services	
Austria	Individual flexibility management contracts
Belgium	Rate flexibility (capacity delivered)
	Volume flexibility (allows to accumulate imbalances)
Germany	Extended balancing (m ³ /h/year)
	Balancing management
Netherlands	Tolerance capacity service (m ³ /h/year)

³ EU 15: Belgium, the Netherlands, G.D. Luxemburg, Germany, France, Italy, UK, Ireland, Denmark, Greece, Spain, Portugal, Austria, Sweden and Finland (Finland was not included in the data from KEMA, 2009)

⁴ Note that the Netherlands are in the process of implementing a new market based balancing mechanism, and that the data in the table is based on the mechanism that was operational in 2008

3.3.3 Inadequate Cost Allocation Leads to Cross-Subsidies

The European practice of providing a longer balancing interval and offering free tolerances actually means giving free short term storage or free short term flexibility. Free in this context means that the costs are socialized in the balancing tariff. So, shippers who need more flexibility, especially intra-day, pay less than the costs they cause to the network system. Shippers who require less flexibility pay more than the costs caused by their actual use of the flexibility. Consequently, this free line-pack flexibility may inhibit the development of other less costly short term flexibility sources, as will be discussed in section 4.

Intra-day flexibility becomes more and more important because of the increasing participation of gas-fired power plants in the gas market. This trend has been observed in recent years and is expected to continue in the next decade (Hallack, 2010). The interdependence of gas and electricity demand profiles (Keyaerts et al., 2010) through these gas-fired power plants increase the short term volatility of gas demand as can be observed in the example of Fig.3. Thus, in a daily balancing model, the flexibility that needs to be provided to accommodate the intra-day demand variability of gas-fired power plants is paid for by all gas shippers, and thus all gas consumers (Costello, 2006; CRE, 2009a). This cross-subsidization decreases the efficiency of the overall gas system efficiency and should, therefore, be addressed.

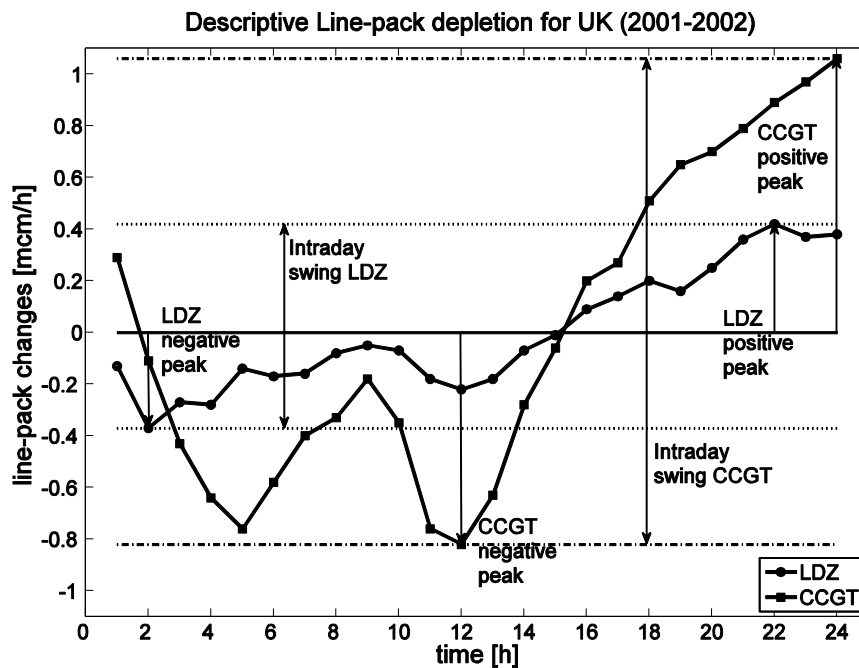


Figure 3: Description of the maximum hourly line-pack depletion for local distribution zones (LDZ) and combined cycle gas turbines (CCGT) in UK (2001-2002) (author elaboration, data from Lapuerta, 2003 and OFGEM, 2003)

In Fig. 3, the changes of hourly gas demand of Combined Cycle Gas Turbines (CCGT) are compared with the demand changes of the Local Distribution Zones (LDZ) of the UK. It can be observed that the changes are much bigger for the CCGT demand, with the biggest negative disequilibrium (withdrawal exceeds injection) amounting to -0.82 million cubic meters (mcm), and the biggest positive disequilibrium (injection exceeding withdrawal) amounting to 1.06 mcm. The respective peaks for LDZ demand are -0.37 and 0.42. The daily swing (the difference between the positive and negative hourly peaks) is 1.88 mcm for CCGTs and 0.79 mcm for LDZ. As the UK balancing charges are based on gas market prices with a daily reference period, it is clear that the LDZ consumers will pay more for their balancing services, due to the flexibility needs of the CCGTs, despite the LDZ not having contributed to the greater costs for the system.

3.4. Conclusion on the Value and Costs of Line-pack Flexibility: Ex Ante Balancing vs. Ex Post Balancing

Line-pack flexibility, as argued above, is a pivotal element in balancing gas networks. In many countries it is the network operator's main tool to perform physical balancing. Implicitly, an imbalance becomes a storage service contract based on line-pack flexibility between the shipper and the system operator. So, with the current balancing framework in mind, the shipper makes a trade-off between *ex ante* balancing and *ex post* balancing. *Ex ante* balancing means contracting a portfolio of flexibility instruments on the market before the imbalance occurs, whereas *ex post* balancing means that the shipper relies on the TSO balancing mechanism. If contracting flexibility is more expensive for the shipper than paying the balancing charges, the shipper will prefer the implicit pipeline storage contract. Consequently, the deployment costs of line-pack flexibility should be properly reflected in the imbalance charges, in order to target the costs to the actual users of the storage services.

In other words, the balancing rules, tariffs and charges in the European network should take into account the real costs of TSOs to provide transport flexibility. This cost reflection issue becomes even more urgent with the changing gas demand profile that is characterized by increasing intra-day volatility as a result of the interaction between the gas and the electricity industry. Nevertheless, in practice, the balancing charges and rules have not been reflecting the network costs, at least not in a transparent way. This is illustrated by the example of the French regulator, who states in its latest deliberation on transport tariffs (CRE, 2009b, p. 2) that “*the first conclusions of the study on the gas infrastructures' capacity to satisfy the electricity power stations' requirements for intra-daily flexibility show that GRTgaz ought to find new internal and external sources of flexibility. GRTgaz has indicated to the CRE that these new requests are likely to mean extra operational costs, [which are] not planned in the current tariff trajectory. The CRE is going to consider how to design a regulated offer of intra-daily flexibility for the users in question. Depending on the progress of this work and if the extra costs presented by the TSOs are confirmed, the CRE may make a new tariff proposal, after consulting with all of the players, in the course of 2010.*”

4. The Market Distorting Consequences of “Imbalanced” Balancing Rules and Tariffs

The choice between balancing *ex ante* or balancing *ex post* implies that line-pack flexibility not only affects the availability of transport capacity, but it also affects the market for other flexibility tools and even the spot market.

So cost allocation and cost reflection are both cornerstones for dealing with line-pack flexibility. A discrepancy in the tariff for the pipeline flexibility service, bundled or unbundled with the transport service, in relation to its true costs has an impact on two parts of the gas industry: the regulated part (allocating costs regardless of the consumer preferences) and the potentially competitive part (building an uncompetitive product regardless of its real cost).

ERGEG (2007, p. 19) has stated: “*Economically, the cost for balancing the transmission network should be made where balancing can be done the cheapest. In other words, the penalties should reflect the actual and efficient cost of balancing the system.*” Economic efficiency is only achieved if the balancing service is provided by whoever can produce the service at lowest costs. However, in a liberalized market the players' decisions are not centralized. So, only if the prices/tariffs reflect the real costs, the players will make the right decisions, and the least expensive balancing tools will be developed. Hence, the importance of the discussion in this paper.

If cash out charges and penalties are high enough, e.g. gas fired power plants may rely less on the *ex post* balancing, and they may prefer to contract more *ex ante* balancing (flexibility in gas commodity contracts, underground storages, LNG storage, or demand side actions) or buy more

network services to allow the revision of their nominations (e.g. hourly) in order to meet their obligations as well as to minimize their costs associated with balancing charges.

4.1. Distorting Effect on the Regulated Infrastructures

Nowadays in the EU gas market, the pipeline flexibility is either unbundled or bundled with other transport services according to the balancing rules. Furthermore, it is subject to regulated prices according to the balancing tariffs, which are linked to a commodity price. As was shown earlier in this paper, these rules and tariffs need to take into account not only the commodity price, but also the cost of the used infrastructure because otherwise perverse incentives can be spread to the transport market and flexibility market. The TSO has to make a trade-off between offering time flexibility and selling transport capacity. The shipper, on the other hand, makes a trade-off between *ex ante* and *ex post* balancing. Clearly both trade-offs are interdependent.

The economic supply function of pipeline storage and pipeline transport can be classified by the classical microeconomics theory as a case of multi-product monopoly where the demand of each product is independent and the costs are dependent, as defined by Tirole (1988). Because the transport market and the flexibility market have different substitutes, they may have a different elasticity. Therefore, it is not possible to solve the pricing problem as a single product monopoly with a sequential solution. Moreover, in the liberalized gas market in Europe, transport is a regulated monopoly, whereas pipeline flexibility is actually in competition with other sources of flexibility, such as contractual flexibility and other storage (IEA, 2002).

The often applied pricing solution of a single regulated tariff for the bundled service results in the earlier identified problem that all network users end up paying for the network flexibility needs caused by a specific group of users. The bundled service tariff is not only inefficient, but it prevents the provision of clear market signals for investment in transport services.

4.2. Distortion of the Competitive Markets

According to the International Energy Agency (IEA, 2002), liberalized gas markets rely on both new market mechanisms and traditional flexibility tools, meaning supply and demand adjustments and storage mechanisms, to match demand and supply over different time horizons. In the same report, the IEA stresses that flexibility is an absolute requirement for the efficient functioning of the gas market. Table 7 provides an overview of flexibility tools that can be used for balancing in different EU countries.

Table 6: Indicative Role of Different Source of Flexibility for System Balancing (KEMA, 2009)

	Line-pack	Production	Storage	LNG	Import
Austria	X		X		X
Belgium	X		X	X	X
Denmark	X	X	X		
France	X		X	X	
Finland	X		X		
Germany	X	X	X		X
Greece	X			X	
Ireland	X		X		
Italy	X		X		
Luxembourg	X				
Netherlands	X	X	X	X	
Portugal	X		X	X	
Spain	X		X	X	
Sweden	X		X		X
United Kingdom	X	X	X	X	

The choice for the most efficient tool should be based on the tool's economic costs and benefits. However, the misallocation of network flexibility does not only provide wrong incentives in the transport service as discussed above, but also in the other segments of the gas industry that are able to deliver short term flexibility: the spot market and the flexibility market.

4.2.1 The Spot Market

According to the IEA (2002), market mechanisms are still the common flexibility providers in most product markets. In the European gas sector, however, complete reliance on only the gas commodity market mechanism for the balancing of demand and supply has not yet been applied because it has high social costs. These social costs can be explained by the analysis of the transaction costs along the industry value chain or by looking at the small price elasticity of demand and supply.

In the literature, it has been underlined many times that various parts of the gas industry chain are subject to high asset specificities, which economically implies that the transaction costs of market coordination are increasing and that the market players are driven to other mechanisms to coordinate the supply of services (Codognet, 2006; Codognet and Glachant, 2006; Creti, 2009; Glachant and Hallack, 2009; Masten and Crocker, 1985; Mulherin, 1986; Neumann and von Hirschhausen, 2006; Spanjer, 2009).

The small price elasticity of supply and demand impedes the market price to achieve the equilibrium where the cost of production would be equal to the value of demand, at least in the short term. The European Commission (2009) reported that the demand elasticity is dependent on the consumer category and the availability of multi-fuel installations. Furthermore, Stern (2009) has demonstrated that even the demand of the consumer category with the biggest elasticity has not been able to respond according to expectations to the price increase in the last years in Europe. Therefore, it can be assumed that the *ex ante* gas market is not a sufficient tool to balance supply and demand in the short term. The inadequate pricing of *ex post* balancing possibly even contributes to the low liquidity in the spot market, if the shipper is better at trading within the balancing mechanism framework than on the spot market. On the supply side domestic production, e.g. in Norway, the UK and the Netherlands, is the main source of flexibility as has been shown by Lapuerta (2003) and Creti (2009). Most of the EU countries have no or very little domestic gas though.

The gas imported from distant sources through very long pipelines can bring some flexibility (European Commission DG Transport and Energy 2008); however, the cost of this flexibility is subject to the same trade-off that has been described earlier in this paper. Moreover, the cost of decreased transport capacity in long distance pipelines may have even higher opportunity costs.

LNG is claimed to be another major source of flexibility allowing a decrease of contract rigidity as demonstrated by Neuhoff and Von Hirschhausen (2005) and allowing more arbitrage as explained by Zhuravleva (2009). However, LNG is still small business in comparison to pipeline gas and it remains a costly tool, which is an argument that will be taken into consideration at the time of a flexibility investment decision.

4.2.2 The Flexibility Market: High Frequency Storage

Pipeline storage differs from traditional underground storage, which usually has a business model with a longer term profile and is dedicated mainly to the seasonal needs. Examples of traditional storages are depleted gas fields or aquifers. These underground storages typically have lower injection and withdrawal rates and large storage capacities allowing only a few cycles (meaning a full loading and unloading of the facility) per year; whereas pipeline storage has a daily cycle and very high deliverability, but is limited in working volume (Clingendael, 2006).

Pipeline storage answers the need for higher frequency balancing, as explained by the European Commission's DG Transport and Energy (2008, p. 69): "*High-frequency optimisation, i.e. optimisation on a daily basis can be regarded as fine-tuning of the stock level. Short term optimisation allows gas market agents to utilise the price differences that exist on a day-to-day basis.*" Still according to the same report of DG TREN, the salt caverns and LNG peak-shaving facilities are the most flexible types of storage because they have higher withdrawal and injection rates compared to aquifers and abandoned fields, but also higher costs. The real cost of a specific storage facility is case dependent, but usually amounts to several hundreds of millions.

So pipeline storage is in competition with these higher frequency traditional storage facilities. The offer of pipeline flexibility is basically a regulated decision, whereas the demand for it depends on the "tariff" to use this flexibility service and on the costs of the other flexibility sources. In order to have an efficient mechanism of storage selection, especially concerning the short term storage, the tariffs should reflect the costs of line-pack flexibility. If the line-pack storage is free to shippers in the short term, they will not have any interest to contract other kinds of storage that can be used with the relevant frequency. In other words, the (competitive) storage market can be distorted because the line-pack flexibility cost are completely carried by the transport network and are socialized by means of transport tariffs, meaning that shippers with a flatter profile subsidize shippers with more volatile consumers (Costello, 2006).

5. Conclusions and Recommendations

As shown in this paper, line-pack flexibility is an important tool with an economic value and cost. However, current gas regulation does not properly take into account the real costs of line-pack flexibility. This inadequate regulation results in market distortions in the regulated transport market, the competitive spot gas market and the market for *ex ante* flexibility. By not considering the true costs of line-pack flexibility, policy makers neglect the market-impeding role of a badly regulated pipeline flexibility service in the choice of the shipper between *ex ante* and *ex post* balancing.

In other words, the balancing service offered by the line-pack flexibility is a valued service. If its cost is socialized, especially by means of the transport tariffs, there is a tendency to have an "over demand" of line-pack flexibility and an "under demand" of transport, because the regulated price passes on the costs to all consumers and not to the actual users of the flexibility. If the flexibility demand is heterogeneous this situation becomes even worse because the flat consumers will subsidize the transport network required by unbalanced shippers.

The market-based solution exists in taking away line-pack flexibility from the regulated system operator and including it in the *ex ante* flexibility market. The price for line-pack flexibility would be set by the marginal unit of flexibility contracted by the market players.

As shown, the gas dynamics behind line-pack flexibility make the complete separation from pipeline transport and pipeline flexibility unlikely. In that case we recommend a different way of calculating a regulated tariff. Because several gas system and market aspects have to be taken into account, the correct pricing of line-pack flexibility, which is a second product offered by the monopoly gas network, is non-trivial. The traditional methodologies to set tariffs for monopoly infrastructures cannot be applied, due to the flexibility product being actually part of an oligopoly market. In this context, the trade-offs and related opportunity costs presented in this paper constitute a framework for policy makers to take into account the costs of line-pack flexibility in the overall network system. Policy makers can evaluate the different trade-offs according to their preferences, implying that different tariffs for line-pack can exist in different gas network systems.

We further recommend that the regulated decision to offer more or less line-pack flexibility should be based on the real network costs and benefits. As there is a trade-off for the TSO between offering transport capacity and offering time flexibility, an additional unit of flexibility comes at the cost of decreased available transport capacity. This cost can be measured by comparing the costs of transport capacity availability with more or less bundled flexibility.

As the evidence in this paper illustrates, further research is required to develop a deeper understanding of the complex interactions between the transport flexibility, the flexibility market, meaning the short term storage, the short term contracts and the flexibility clauses of the long term contracts. The calculation of the identified inefficiencies in practice would give a better insight into the money on the table. This exercise would be beyond the scope of this paper, but is intended in further research.

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References

- Clingendael International Energy Programme, 2006. The European Market for Seasonal Storage, Clingendael Discussion Papers. Clingendael Institute, The Hague.
- Coase, R.H., 1960. The Problem of Social Cost. *The Journal of Law and Economics* 3, 1-44.
- Codognet, M.K., 2006. L'analyse économique des contrats d'accès aux réseaux dans les réformes concurrentielles gazières, doctoral dissertation. Université Paris Sud XI, Paris, France.
- Codognet, M.K., Glachant, J.-M., 2006. Weak investments Incentives in New Gas Storage in the UK?, 29th IAEE International Conference. IAEE, Potsdam, Germany.
- Costello, K., 2006. Efforts to Harmonize Gas Pipeline Operations with the Demands of the Electricity Sector. *The Electricity Journal* 19, 7-26.
- CRE, 2009a. Consultation publique: Principes relatifs à l'acheminement du gaz pour les centrales de production d'électricité raccordées aux réseaux de transport de gaz naturel.
- CRE, 2009b. Délibération de la CRE du 3 décembre 2009 portant proposition de modification des tarifs d'utilisation des réseaux de transport de gaz naturel.
- Creti, A., 2009. *The Economics of Natural Gas Storage: A European Perspective*. Springer Berlin Heidelberg, Berlin.
- Eberhard, R., Hüning, R., 1990. *Handbuch der Gasversorgungstechnik, Gastransport und Gasverteilung*, 2 ed. Oldenbourg.
- ERGEG, 2006. Guidelines of Good Practice for Gas Balancing, in: ERGEG (Ed.). European Regulators Group for Electricity and Gas, Brussels.
- ERGEG, 2007. Gas Transmission Tariffs: an ERGEG Benchmarking Report, in: ERGEG (Ed.). European Regulators Group for Electricity and Gas, Brussels.
- ERGEG, 2009. ERGEG Principles Capacity Allocation and Congestion Management in European Gas Transmission Networks, in: ERGEG (Ed.). European Regulators Group for Electricity and Gas, Brussels.
- European Commission, 2009. Commission Staff Working Document, Assessment Report of Directive 2004/67/EC on Security of Gas Supply, Commission Staff Working Document accompanying proposal for a Regulation of the European Parliament and of the Council concerning measures to safeguard security of gas supply and repealing Directive 2004/67/EC. European Commission, Brussels.
- European Commission DG Transport and Energy, 2005. Benchmarking report. European Commission, Brussels.
- European Commission DG Transport and Energy 2008. Draft Final Report on Study on Natural Gas Storage in the EU. European Commission, Brussels.
- European Union, 2009a. Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC, in: European Union (Ed.). Official Journal of the European Union, L 211, pp. 94-136.
- European Union, 2009b. Regulation (EC) 715/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for the access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005, in: European Union (Ed.). Official Journal of the European Union, L 211, pp. 36-54.
- Glachant, J.-M., 2002. Why Regulate Deregulated Network Industries? *Journal of Network Industries* 3, 297-311.
- Glachant, J.-M., Hallack, M., 2009. Take-or-Pay Contract Robustness: A Three-Step Story Told by the Brazil-Bolivia Gas Case? *Energy Policy* 37, 651 - 657.
- Glachant, J.-M., Perez, Y., 2007. Institutional Economics and Network Deregulation Policy, Université Paris sud working paper.
- GRTgaz, 2009. Note d'intention: Offre de transfert pour la flexibilité nécessaire aux cycles combinés gaz.
- GTE, 2009. Report on a benchmark among GTE members to assess difficulties in the application of the current GGP on gas balancing. Gas Infrastructure Europe, Brussels.
- Hallack, M., 2010. The New EU Gas Demand Driven by the Increase Incorporation of Gas-Fired Power Plants Impacts the Gas Transport Network, doctoral dissertation. University of Paris Sud XI, Paris, France.
- IEA, 2002. Flexibility in Natural Gas Supply and Demand. OECD/IEA, Paris.

- Joskow, P., 2007. Supply Security in Competitive Electricity and Natural Gas Markets, in: Robinson, C. (Ed.), *Utility Regulation in Competitive Markets* Edward Elgar Publishing, Cheltenham, pp. 82-118.
- Kahn, A., 1971. *The Economics of Regulation: Principles and Institutions* (vol. 2). John Wiley & Sons.
- KEMA, 2009. Study on Methodology for Gas Transmission Network Tariffs and Gas Balancing Fees in Europe. Report ordered by European Commission DG TREN.
- Keyaerts, N., Meeus, L., D'Haeseleer, W., 2008. Analysis of Balancing-System Design and Contracting Behaviour in the Natural Gas Markets, European Doctoral Seminar on Natural Gas Research, Delft, The Netherlands, 24 October 2008.
- Keyaerts, N., Rombauts, Y., Delarue, E., D'haeseleer, W., 2010. Impact of Wind Power on Natural Gas Markets: Inter-Market Flexibility, 7th Conference on the European Energy Market 2010, Madrid, Spain.
- Lapuerta, C., 2003. Brattle's Assessment of the Operation of the NTS, in: OFGEM (Ed.), *The Gas Trading Arrangement: Reform of the Gas Balancing Regimes*. The Brattle group.
- Lapuerta, C., Moselle, B., 2002. Convergence of Non-Discriminatory Tariff and Congestion Management Systems in the European Gas Sector. The Brattle Group.
- Masten, S.E., Crocker, K.J., 1985. Efficient Adaptation in Long-Term Contracts: Take-or-Pay Provisions for Natural Gas. *The American Economic Review* 75, 1083-1093.
- Mulherin, J.H., 1986. Complexity in Long-Term Contracts: An Analysis of Natural Gas Contractual Provisions. *Journal of Law, Economics and Organization* 2, 105-117.
- Neuhoff, K., von Hirschhausen, C., 2005. Long-Term vs. Short-Term Contracts; A European Perspective on Natural Gas, Cambridge Working Papers in Economics. Faculty of Economics, University of Cambridge.
- Neumann, A., von Hirschhausen, C., 2006. Long-Term Contracts and Asset Specificity Revisited -An Empirical Analysis of Producer-Importer Relations in the Natural Gas Industry, Cambridge Working Papers in Economics. Faculty of Economics, University of Cambridge.
- OFGEM, 2003. *The Gas Trading Arrangement: Reform of the Gas Balancing Regimes*.
- Oren, S., Sioshansi, R., 2004. Joint Energy and Reserves Auction with Opportunity Cost Payment for Reserves, Proceedings of the Bulk Power System Dynamics and Control VI, Cortina D'Ampezzo, Italy, p. 6.
- Pineau, P.-O., Lefebvre, V., 2009. The Value of Unused Transmission: Estimating the Opportunity Cost for the Province of Quebec, Canada, Proceedings of the 32nd IAEE International Conference 2009, San Francisco, USA.
- Rious, V., Dessante, P., Glachant, J.-M., 2008a. Anticipation for Efficient Electricity Transmission Network Investments, 1st International scientific conference "Building Networks for a Brighter Future" organized by NGInfra and sponsored by IEEE Systems, Man & Cybernetics Society, Rotterdam, the Netherlands.
- Rious, V., Glachant, J.-M., Perez, Y., Dessante, P., 2008b. The Diversity of Design of TSOs. *Energy Policy* 36, 3323 - 3332.
- Spanjer, A.R., 2009. Regulatory Intervention on the Dynamic European Gas Market--Neoclassical Economics or Transaction Cost Economics? *Energy Policy* 37, 3250 - 3258.
- Spulber, D.F., 1989. *Regulation and Markets*. The MIT Press.
- Stern, J., 2009. Continental European Long Term Gas Contracts: Is a Shift away from Oil-Linked Pricing Inevitable?, Oxford Institute for Energy Studies Working Papers 34. OIES, p. 29.
- Tirole, J., 1988. *The Theory of Industrial Organization*. The MIT Press - Cambridge.
- Zhuravleva, P., 2009. The Nature of LNG Arbitrage: An Analysis of the Main Barriers to the Growth of the Global LNG Arbitrage Market, Oxford Institute for Energy Studies Working Papers 31. OIES, p. 29.

Appendix

5. Load Management and the Deployment of the Line-pack Buffer

Fig.4 illustrates how line-pack flexibility supports intra-day load management. If the shipper injects all his gas during the first half of the day (subfigure a), a buffer is built up for withdrawal during the second half of the day (subfigure b). The pipelines are turned into gas storage. If the shipper injects late, meaning in the second half of the day (subfigure c), gas is withdrawn from the line-pack buffer during the first 12 hours (subfigure c).

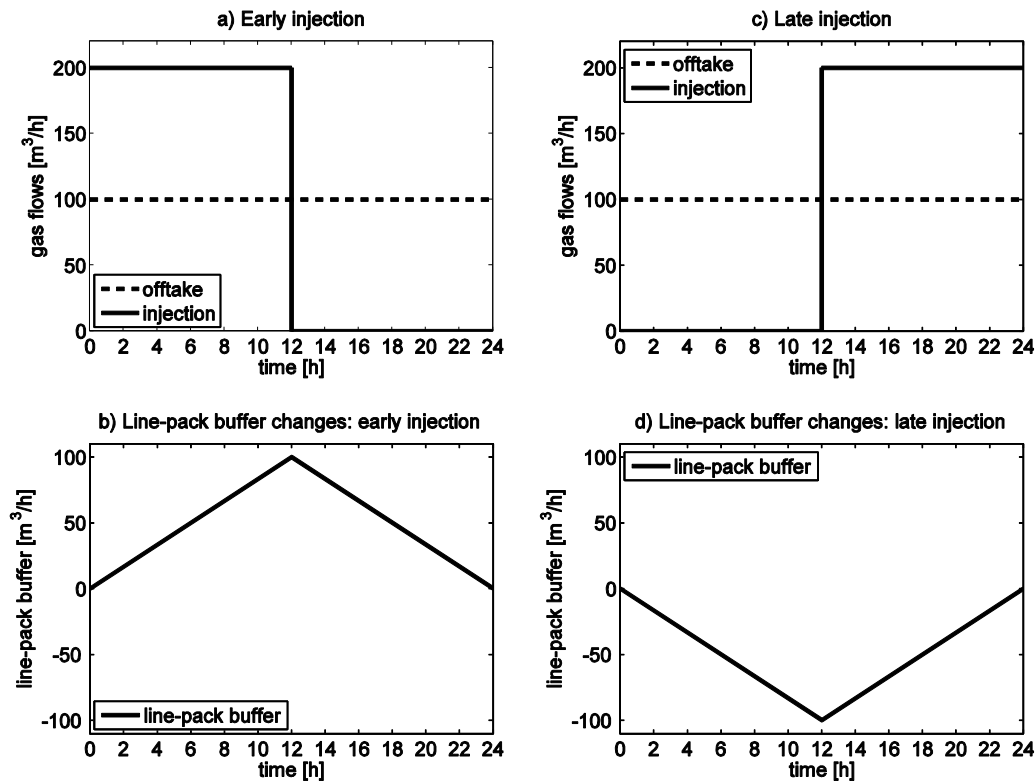


Figure 4: Load Management by Means of Line-pack Flexibility (based on Lapuerta 2003)

In both examples the shipper needs entry capacity of 200 (MWh/h) and exit capacity of 100 (MWh/h). So, the shipper counts on the pipeline storage to balance the actual loads. If the shipper injects before he withdraws the system operator only has to allocate physical pipeline capacity to the build-up of the buffer with a maximum size of 100 MWh at midday. Consequently, the TSO cannot sell 100 MWh/h of the transport capacity. If the shipper withdraws gas before he injects it, the TSO responds, or rather has to anticipate the use of buffer gas, meaning the TSO cannot sell 100 MWh/h of the transport capacity. Moreover, the TSO has to provide buffer gas that will be withdrawn by the shipper before noon. In the afternoon the buffer is replenished by the shipper. The opportunity cost of the unsold capacity is dependent on the size of the capacity that is kept off the market. This size can be related to the biggest cumulative swing in either direction (Fig. 4b and 4d). Therefore, the price of balancing services should preferably be related to the peak cumulative imbalance.