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Natural Gas Storages in Competition with Alternative Flexibility Sources

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Contents:

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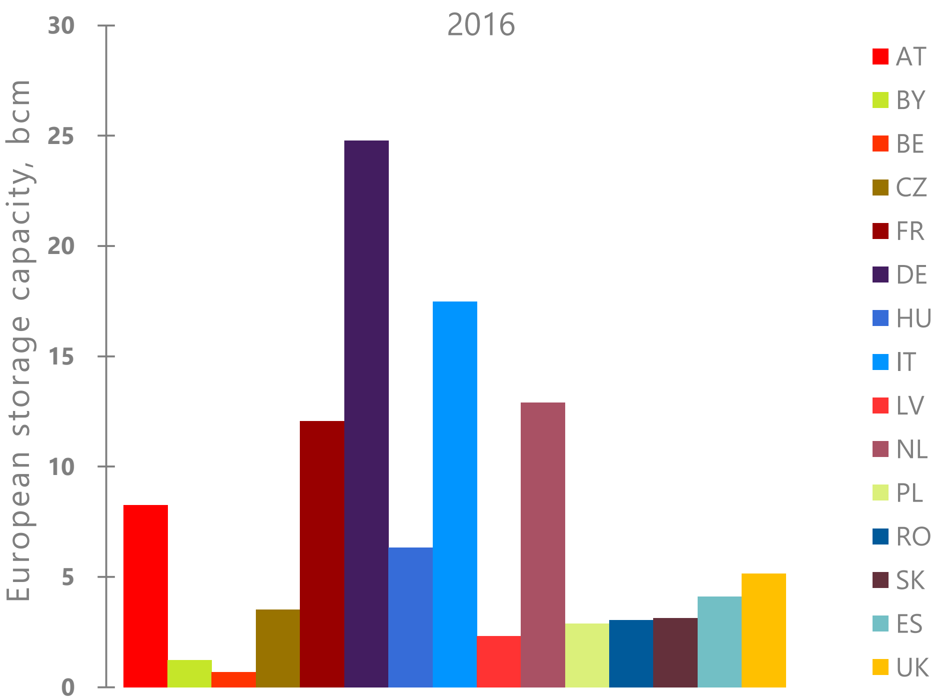
Gas storages were always considered a key factor in the provision of flexibility and security for gas supplies. Storage capacities in EU28 reached 94.5 BCM on Jan 2016. This amounts to a raise of about 40 % over the last 10 years.

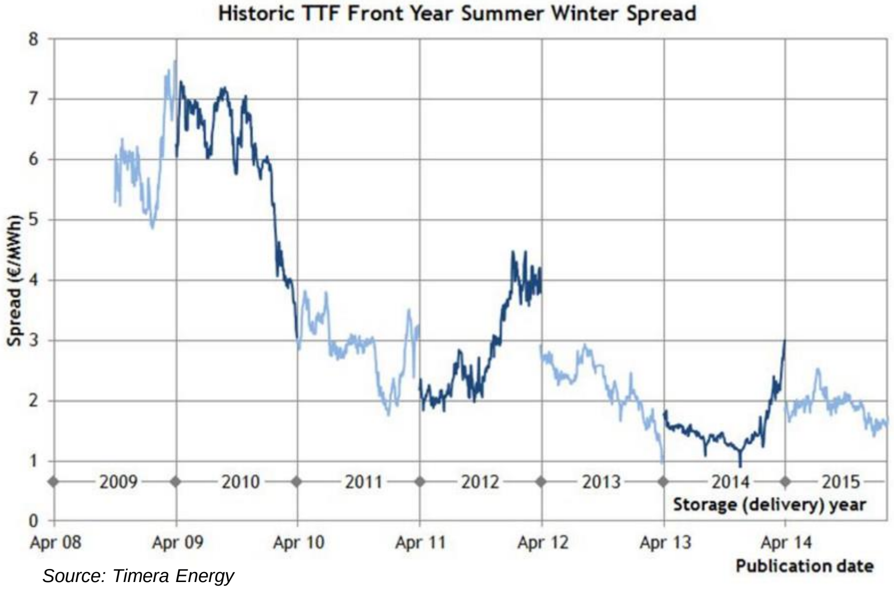


Sources: GSE 2016, NAFTOGAZ

However, storages compete with other flexibility options such as:

- ✓ Flexible domestic production
- ✓ Variation in pipeline imports (pipeline swing)
- ✓ Variation in supply by LNG imports
- ✓ Demand side response

Research question: may storage capacity utilization be on a declining path, as its main economic driver (W-S spread) significantly dropped and other competing flexibility tools, like pipeline/LNG imports may be on the rise?



The objective of this work is to analyze the future role of storages and their position in competition with other flexibility sources to meet European countries' specific demand fluctuations.

Contents:

Employed gas market model

Model focus

- The model simulates operation of European gas sector in a middle- and long terms

Model formulation

- Model is formulated as a social-welfare optimization problem*
- Mathematical framework: nonlinear programming
- Implemented with GAMS (IPOPT solver) / VBA

Key features

- Separation between traded & physical gas flow volumes
- Demand response to price (affine demand function)
- Golombek production costs (logarithmic cost functions)
- Incorporation of long-term contracts closures
- Monthly time resolution

Model major input data

- Geographical scope for this work: Europe, FSU, North Africa and Qatar*
- Natural gas pipeline infrastructure and development plan (sources: ENTSOG, NAFTOGAZ, GAZPROM)
- LNG liquefaction and regasification terminals (source: GIE)
- Gas storage facilities (source: GSE)
- Long-term contracts (source: DIW Berlin, GIIGNL)
- General market information (major sources in Appendix A)

** Model formulation and geographical scope may vary with the research objectives. The model package allows Mixed Complementarity Problem (MCP) formulation.*

Model structure: schematic overview

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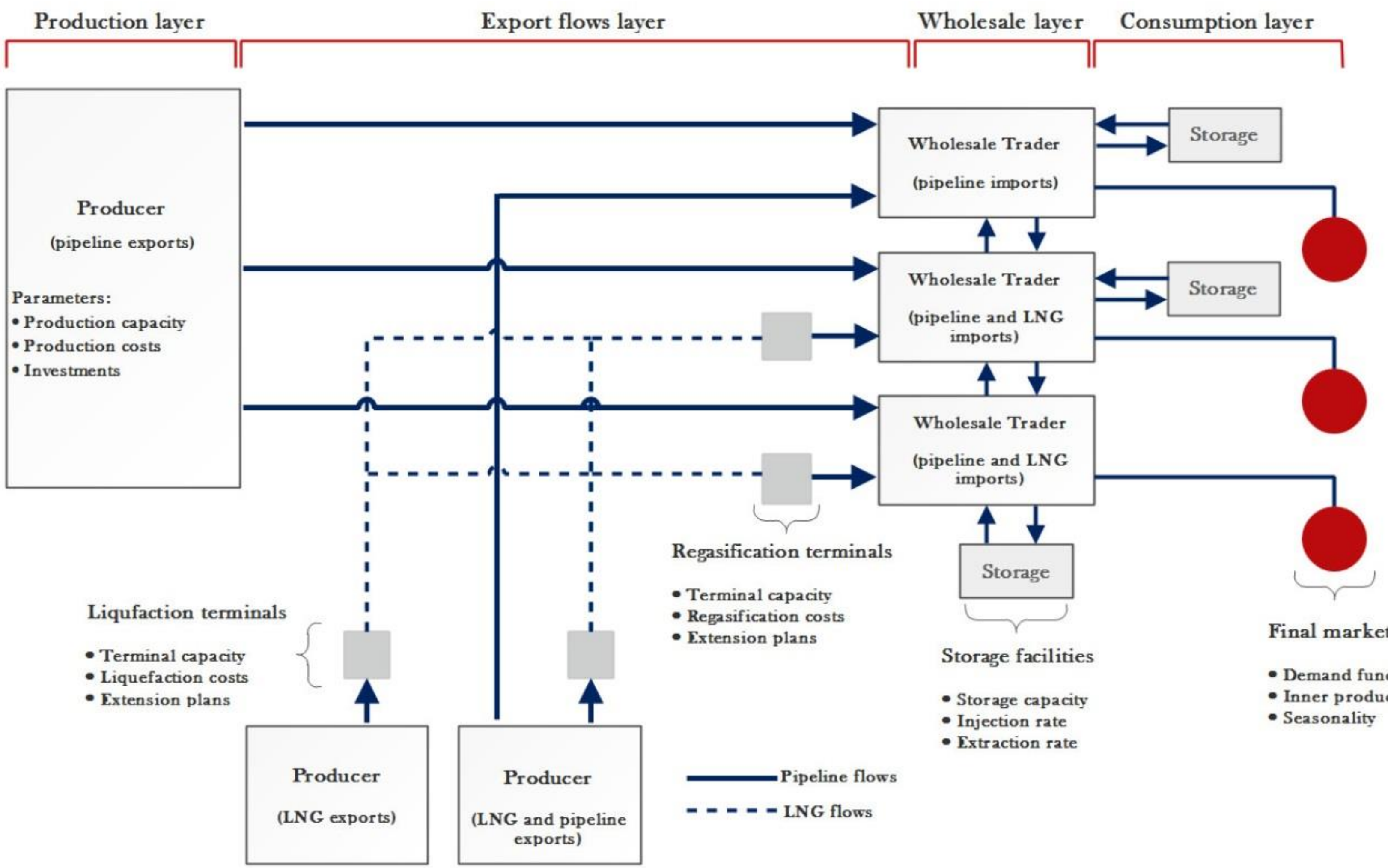

Contents:

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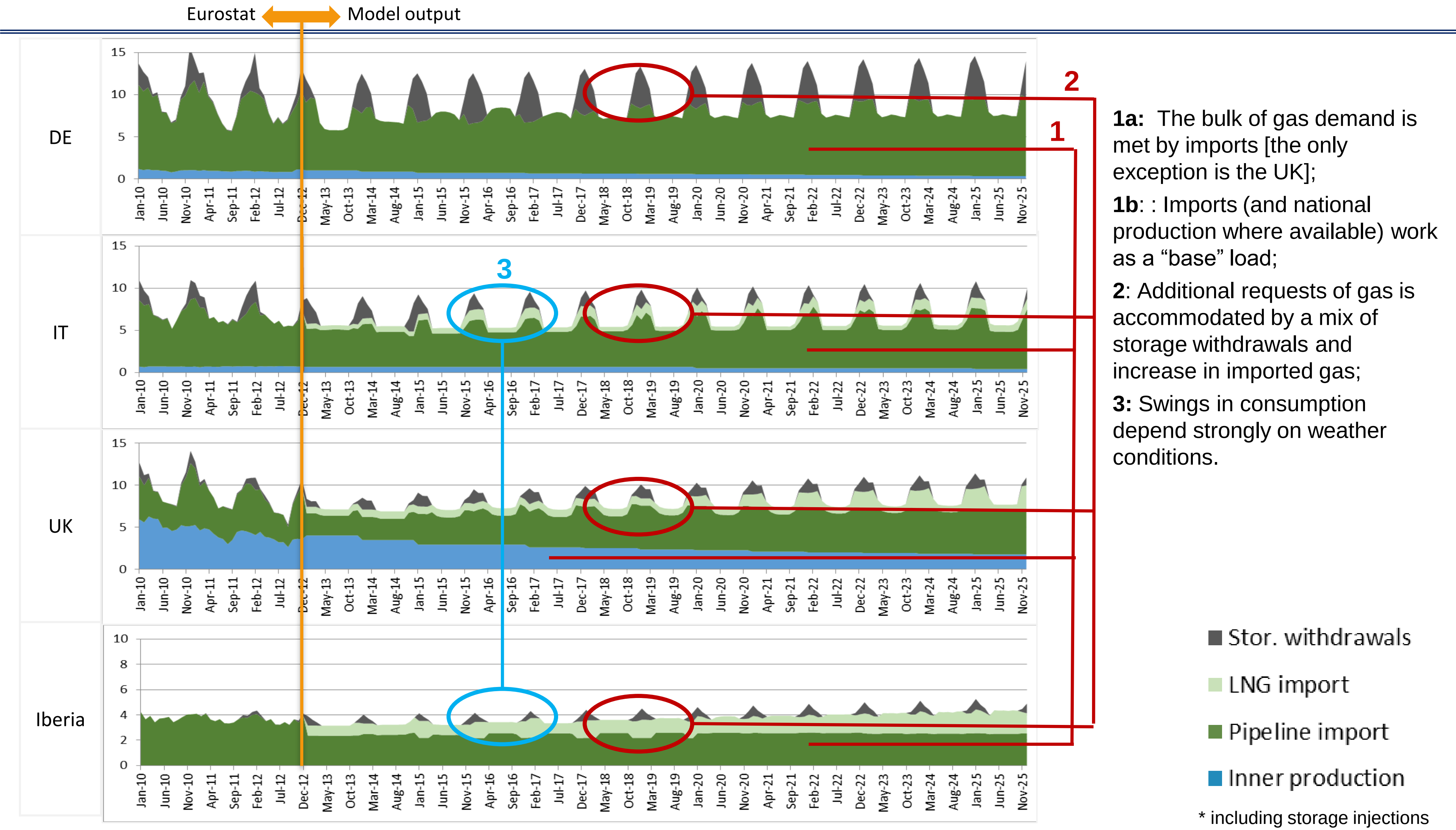
Gas demand* fluctuations for selected countries



1a: The bulk of gas demand is met by imports [the only exception is the UK];

1b: : Imports (and national production where available) work as a "base" load;

2: Additional requests of gas is accommodated by a mix of storage withdrawals and increase in imported gas;

3: Swings in consumption depend strongly on weather conditions.

* including storage injections

Shares of different sources for covering annual gas demand: reference model dispatch

1a: Average share (per year) of storage withdrawals in fulfilling seasonal demand swing ranges from 4% in Iberia to18.5% in France;

1b: For the reference model dispatch, German storages cover in average 13.5% gas demand per year (10% based only on Eurostat data);

Share of storages in annual supply mix does not change significantly during the modelling period;

2: In general, there is no clear trend in historic data that the relative share of storage weight depends on market maturity.

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The coefficient of variation (CV or RSD) is defined as the ratio of the standard deviation to the mean:

$$C_v = \frac{\sigma}{\bar{x}} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2}}{\bar{x}}$$

- CV allows for meaningful comparisons between two or more magnitudes of variation, even if they have different means or different scales of measurement.
- In our case, it helps to answer the question: **which source brings most flexibility to meet demand fluctuations?**

Which source brings most flexibility to meet demand fluctuations?

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Country	Inner production*	Pipeline import	LNG import	Stor. withdrawals
DE	0.11	0.17		0.77
FR		0.33	0.48	0.43
IT	0.04	0.19	0.41	0.86
PL	0.08	0.18		0.49
CZ		0.33		0.44
AT		0.19		0.35
BE		0.44	0.73	0.38
UK	0.20	0.23	0.46	0.52
HU	0.07	0.41		0.63
RO	0.05	0.36		0.43
Iberia		0.06	0.26	0.55

** Based on Eurostat data*

1: Utilization of storages and LNG terminals, in relative terms, is always more flexible than import supply -> deliveries from storage facilities are reduced and increased more remarkably than imports;

2: Storages and LNG bring most of supply flexibility required to meet demand fluctuations;

3: National production (exception: UK and Netherlands) plays a minor role in fulfilling demand swing.

Coefficient of variation yearly for selected countries

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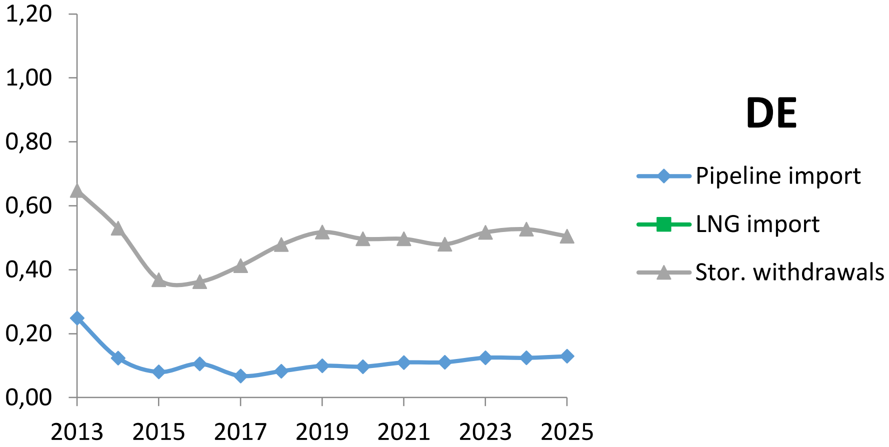
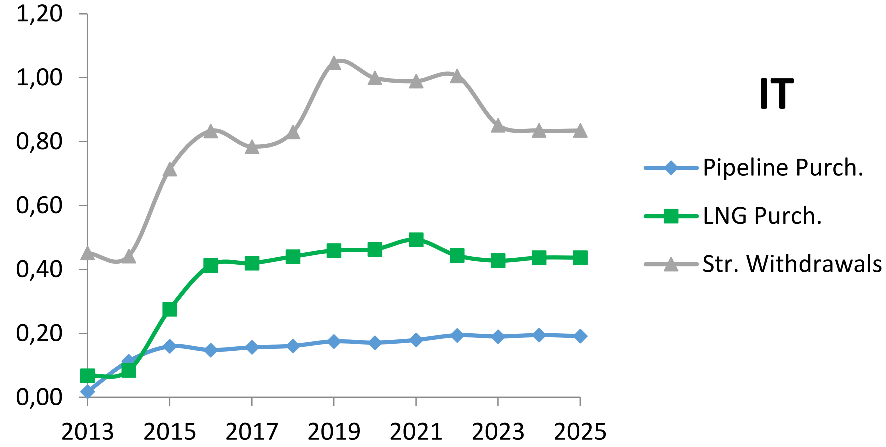
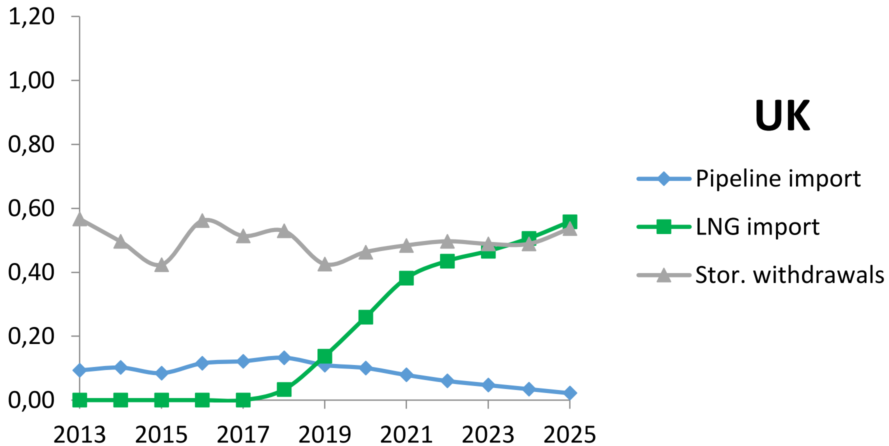
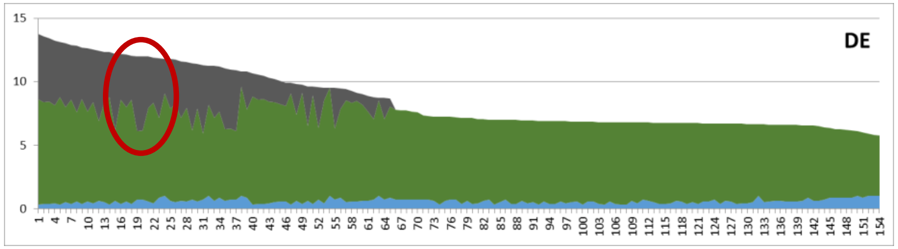




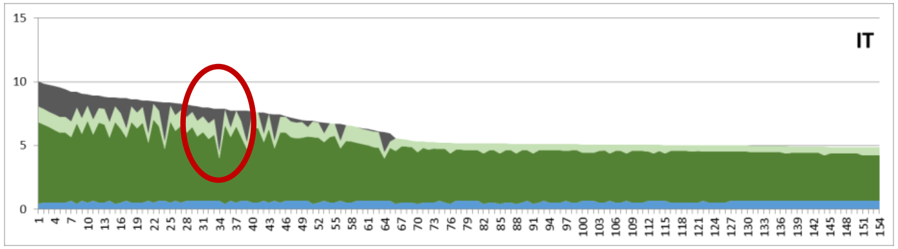


- Contribution of LNG import fluctuations to the coverage of demand swing tend to increase over time, displacing some pipeline imports flexibility (UK);
- The role of storage flexibility in meeting seasonal demand is either stable (DE, UK) or increasing (IT).

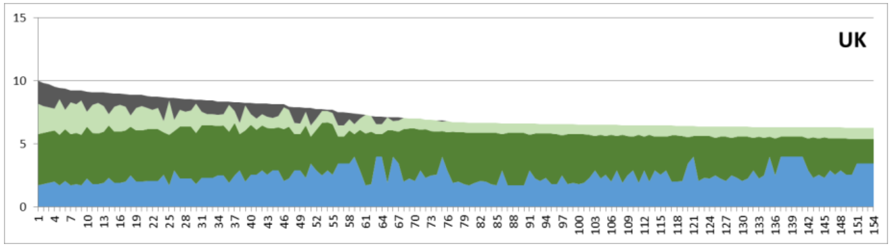
Load duration curves for selected countries



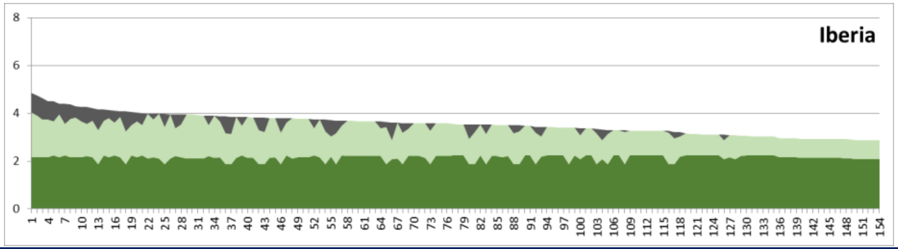
DE	Max	Average
Inner production	17.35%	7.46%
Pipeline import	95.57%	81.05%
LNG import	0.00%	0.00%
Stor. withdrawals	49.53%	28.02%



IT	Max	Average
Inner production	13.81%	9.90%
Pipeline import	81.42%	73.11%
LNG import	20.05%	12.17%
Stor. withdrawals	42.92%	11.56%



UK	Max	Average
Inner production	63.22%	35.24%
Pipeline import	62.22%	46.13%
LNG import	31.13%	14.11%
Stor. withdrawals	21.69%	10.84%



Iberia	Max	Average
Inner production	0.00%	0.00%
Pipeline import	73.90%	60.99%
LNG import	46.74%	34.43%
Stor. withdrawals	21.11%	11.00%

Summing up reference scenario:

- ✓ Indigenous natural gas production and pipeline imports have relatively low contribution to provision of seasonal flexibility.
- ✓ Increasing competition in the market for flexibility did not result in storage being significantly underutilized: storages have been constantly refilled with high rates over the whole modelling period.
- ✓ Storage importance in fulfilling demand fluctuations remain on a high level for peak load levels over the whole modelling period.

Germany: transmission capacity scenarios

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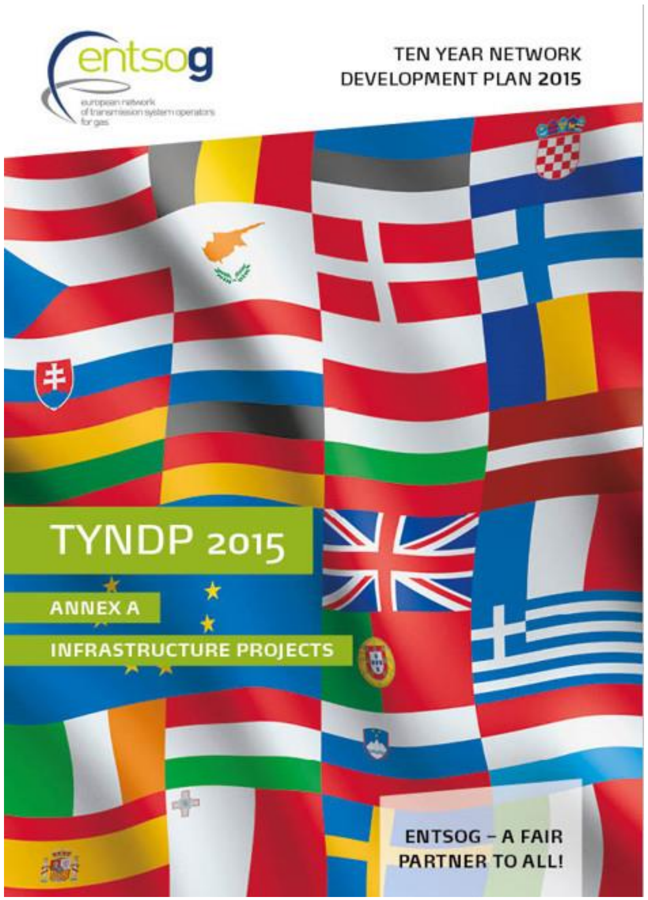

entsog

Twenty-Year Network Development Plan 2015
Annex A

Data tables: Infrastructure Projects

“Reference” scenario:

- Includes only “post FID” gas infrastructure capacity enhancements
- Nord stream 2 [55 bcm] comes into operation on 2021

“High trans cap” scenario:

- Includes also “Most likely” infrastructure capacity enhancements
- Includes planned LNG terminals
- Nord stream 2 [55 bcm] comes into operation on 2018

Germany: LDCs for transmission capacity scenarios

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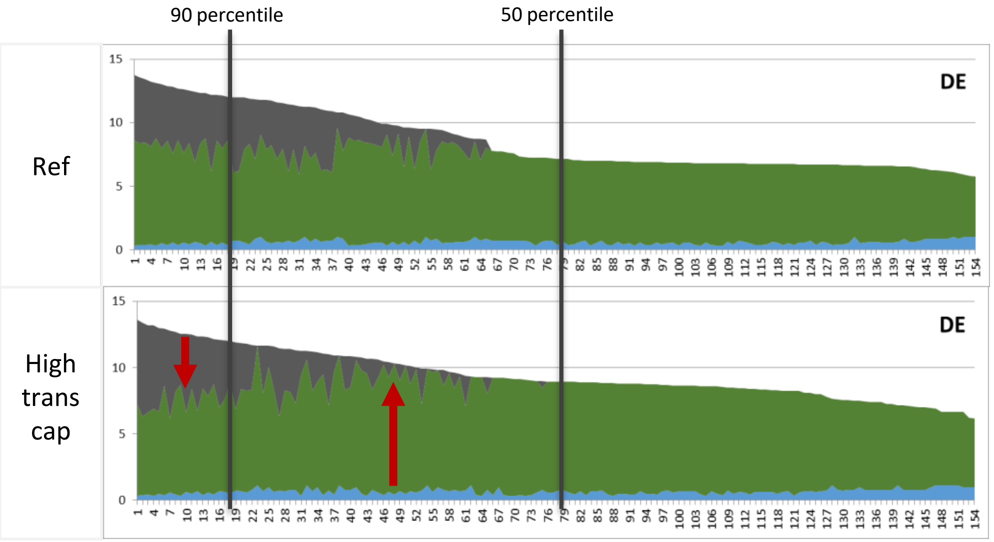

Germany	Max	Average
Reference		
Inner production	17.35%	7.46%
Pipeline import	95.57%	81.05%
Stor. withdrawals	49.53%	28.02%
High transmission capacity		
Inner production	16.99%	7.57%
Pipeline import	96.09%	83.27%
Stor. withdrawals	52.86%	22.00%

1: The role of pipeline imports increase [due to higher transmission capacity], substituting storage utilization for “intermediate load” times;

2a: While for “peak load” times storage flexibility still has high share [for majority of counties];

2b: Furthermore, storage supply during the highest load times in even increase.

Italy: LNG capacity & cost scenarios

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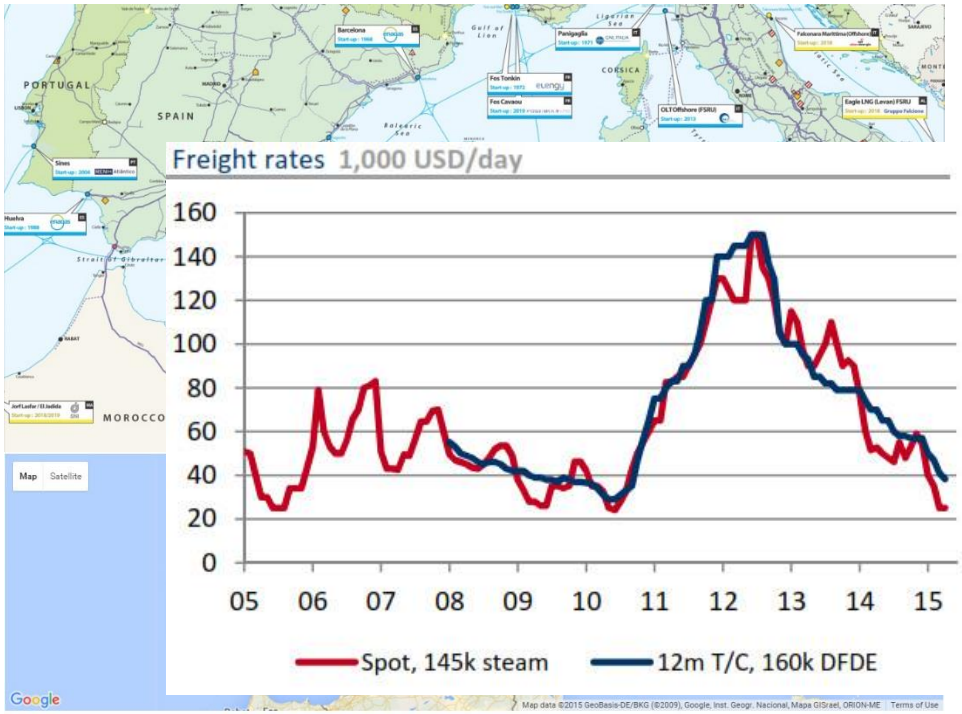

Shipping cost follow own estimation based on:

- Geographical location of corresponding harbors and sea distances
- Average speed of tankers
- Average LNG vessel size
- Average charter rate fee per day

Reference values in Euro/MWh for route Qatar->Italy:

- Liquefaction fee: 3.7
- Shipping Fee: 1.4
- Regasification fee: 0.7

LNG terminals data, top:
GIE LNG MAP 2015

Sea distances calculation, bottom:
http://www.sea-distances.org

Freight rates data:
RS Platou Monthly (April 15)

Italy: LNG capacity & cost scenarios

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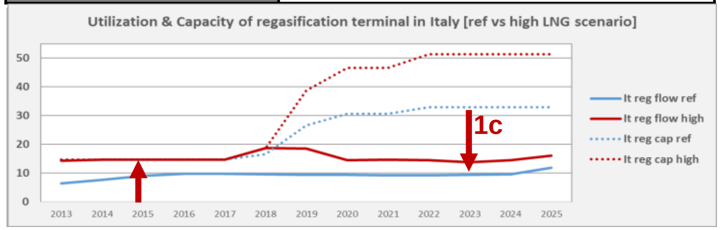
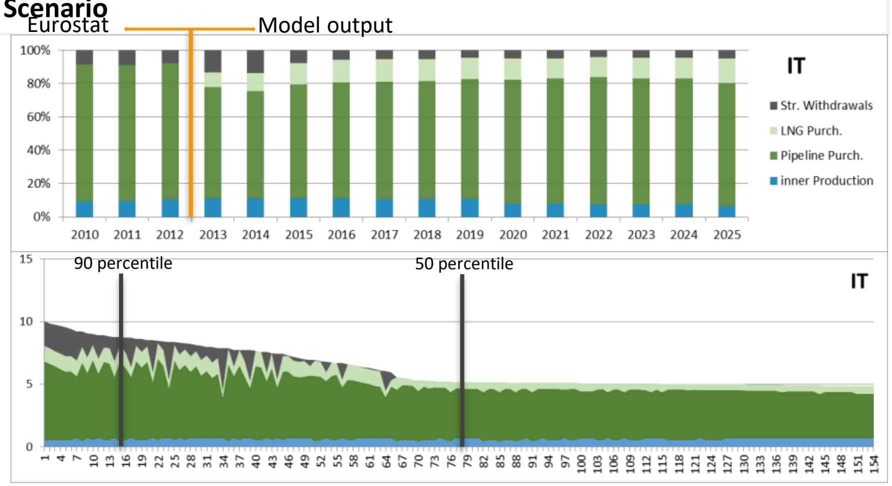
Reference Scenario

Reference	Max	Average
Inner production	13.81%	9.90%
Pipeline import	81.42%	73.11%
LNG import	20.05%	12.17%
Stor. withdrawals	42.92%	11.56%



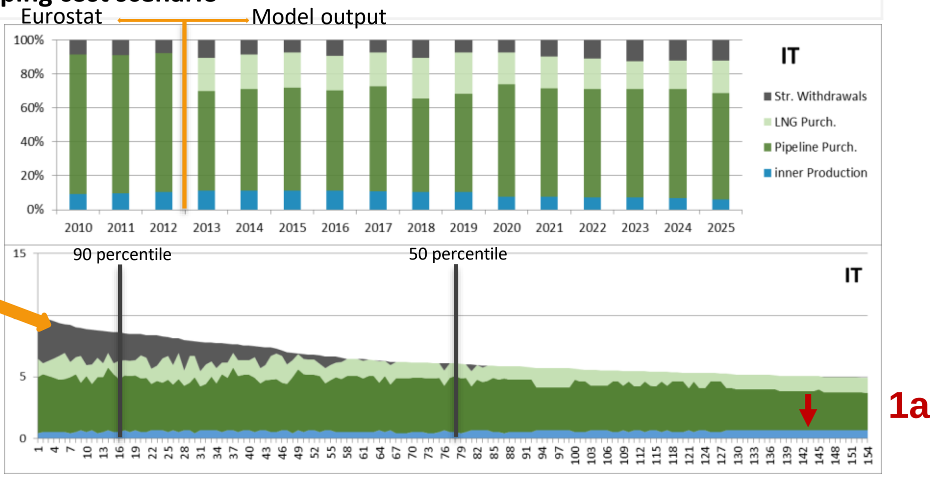


50% lower LNG shipping cost scenario

Reference	Max	Average
Inner production	14.36%	9.47%
Pipeline import	78.30%	62.81%
LNG import	30.67%	20.10%
Stor. withdrawals	37.92%	18.59%

1b

2



1a: Increased LNG imports displace most expensive pipeline imports [mainly in “base -” and “intermediate load” times];

1b: Average LNG share increases from 12.2% to 20.1%;

1c: For first years utilization of regas. terminal raises from app. 50% till 100%; after 2020 it is underutilized in all scen. though;

2: Average storage utilization remains high for “peak load”;

Summing up scenario runs:

- ✓ The value of seasonal flexibility provided by storage facilities differ broadly across European countries and depends on energy mix, consumption structure, macroeconomics and political decisions;
- ✓ There is no clear evidence that in favorable conditions other sources of flexibility (LNG or flexible pipeline imports) may in long term displace storages from the position of the important provider of seasonal flexibility.

Self-criticism

- Neglecting long-term storage contracts [data is not disclosed]
  - Result: “This may contribute to the fact that, although the price incentive to use storage is low (due to low summer-winter spread and subdued price volatility), storages in Europe have been constantly refilled at very high rates” (EC, 2015).
  - No evidence that existing long term storage contracts will be extended.
- Neglecting storage extrinsic value and system safety needs [model formulation]
- Neglecting short-term volatility of demand [model formulation] *(to be done)*
- Weak assumptions about production capacities&costs [data is scarce]
- Model results strongly depend on set of assumptions

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THANK YOU!

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Appendix A: major data sources

http://www.entsog.eu/

http://www.gie.eu.com/

http://www.naturalgaseurope.com/

http://www.iea.org/

http://www.bp.com/en/global/corporate/energy-economics/

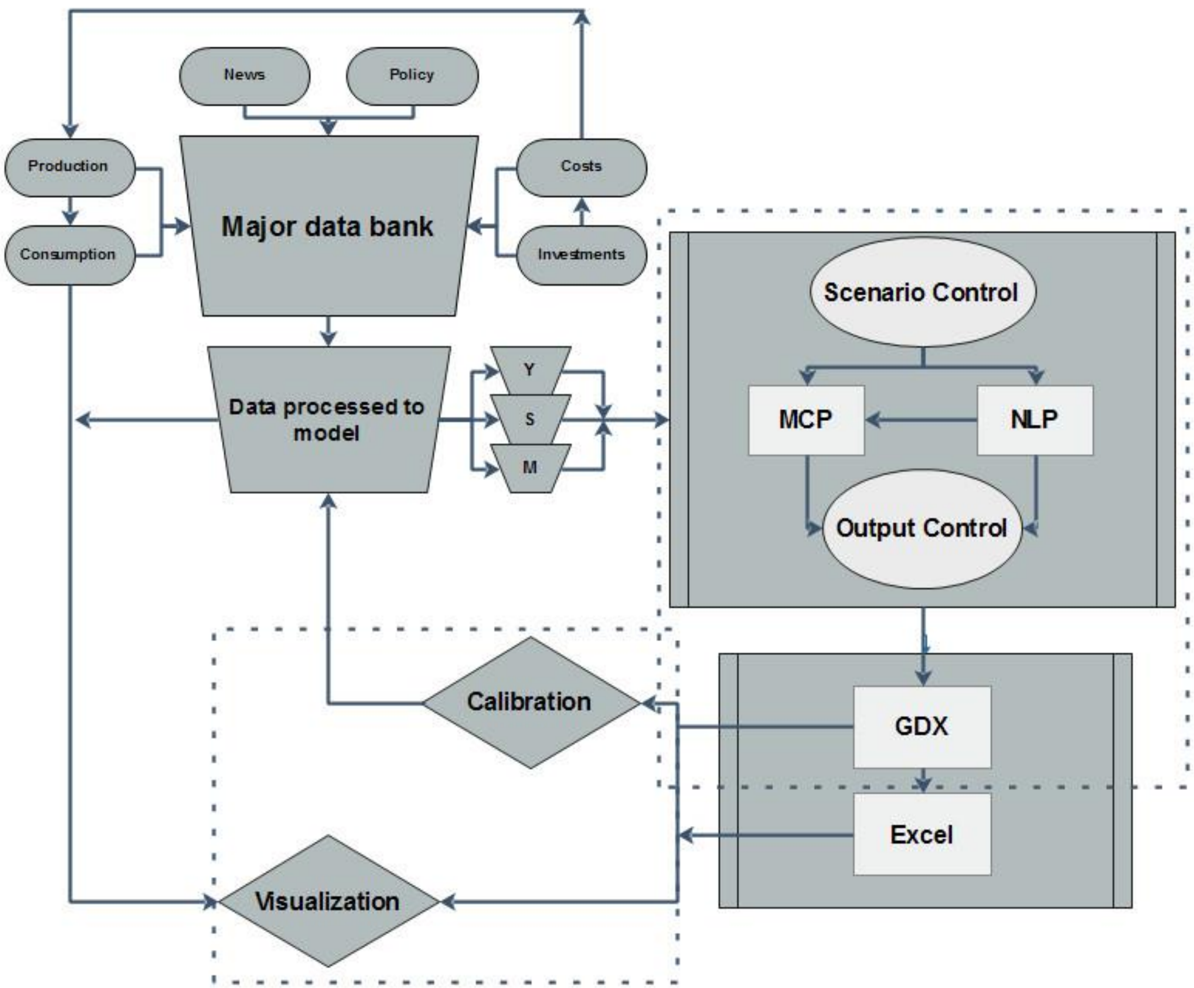
http://www.eia.gov/

http://ec.europa.eu/eurostat/web/energy/data/database

http://www.sea-distances.org/

http://www.timera-energy.com/

Appendix B: model architecture



Appendix C: Social welfare optimization function and sources of non-linearities

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Objective function:

$$max\,W = ConSur + ProdRev - Cost^{Prod} - Cost^{Transport} - Cost^{Storage}$$

Where:

$$ConSur = 0{,}5 \cdot \sum_{n,t} [(a_{n,t} - price_{n,t}) \cdot cons_{n,t}]$$

$$price_{n,t} = price^{ref}_{n,t} - b_{n,t} \cdot cons^{ref}_{n,t} + \frac{price^{ref}_{n,t}}{cons^{ref}_{n,t}} \cdot \frac{1}{\sigma^{dem}_{n}} \cdot cons_{n,t}$$

$$ProdRev = \sum_{p,n,m,t} (exp_{p,n\to m,t} \cdot price_{m,t})$$

$$Cost^{Prod} = \sum_{p,n,m,t} (exp_{p,n\to m,t} \cdot mpc^{prod}_{n,t})$$

$$mpc^{prod}_{n,t} = \alpha + \beta \cdot Volume + \gamma \cdot \ln(1 - \frac{Volume}{Capacity})$$

$$Cost^{Transport} = \sum_{p,n,m,t} (expfl_{p,n\to m,t} \cdot mtc^{pipe}_{n\to m,t})$$

$$Cost^{Storage} = \left(\sum_{n,t} store^{in}_{n,t} \cdot cost^{store.in}_{n} + store^{out}_{n,t} \cdot cost^{store.out}_{n}\right)$$

n, m	Nodes in the model
p	natural gas Producers (upstream players)
t	Time periods

Appendix D: Demand function

The affine inverse demand function:

$$P(Q) = a + b \cdot Q$$

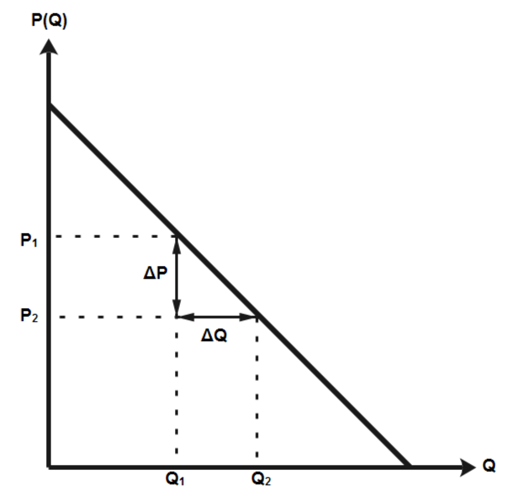
Estimation of inverse demand function is done around the reference point *(p^{ref}, Q^{ref})*:

$$P^{ref} = a + b \cdot Q^{ref}$$

Using notion of PED (ε) following definitions can be written :

$$Q = -\frac{a}{b} + \frac{1}{b} \cdot p \qquad \varepsilon = -\frac{\partial Q}{\partial p} \cdot \frac{p}{Q} = \frac{1}{b} \cdot \frac{p}{Q}$$

$$b = \frac{p}{Q} \cdot \frac{1}{\varepsilon} \qquad a = p - b \cdot Q$$



Inserting it to the affine demand function:

$$p = P^{ref} - b \cdot Q^{ref} + \frac{P^{ref}}{Q^{ref}} \cdot \frac{1}{\varepsilon} \cdot Q$$