european network
of transmission system operators
for gas

# TEN-YEAR NETWORK DEVELOPMENT PLAN 2017

# TYNDP 2017

## ANNEX F

## METHODOLOGY

**ENTSOG – A FAIR PARTNER TO ALL!**

# 1 General considerations on the ESW-CBA Methodology

Following the requirements of the New TEN-E Regulation, ENTSOG has developed an Energy System-Wide Cost-Benefit Analysis (CBA) methodology supporting the selection of Projects of Common Interest (PCI).

This methodology is composed of a TYNDP-Step, which is a part of this Report, and a Project Specific-Step to be applied by promoters of projects which are candidates for PCI status, the first step being an enabler of the latter. Therefore, the inclusion in the TYNDP and its assessment is an important prerequisite for projects to become a PCI later on. The CBA methodology was approved by the European Commission on 4 February 2015.

This annex links the TYNDP 2017 report to the CBA methodology[1)] by describing the implementation of the CBA methodology in the context of the TYNDP 2017. It focuses on that part of the methodology, which has been applied for the TYNDP 2017 report.

ENTSOG has defined the infrastructure-related market integration as a physical situation of the interconnected network which, under optimum operation of the system, provides sufficient flexibility to accommodate variable flow patterns that result from varying market situations. In addition to its embedded value, market integration sustains the pillars of the European energy policy (Security of Supply, Competition and Sustainability). These four aspects define the specific criteria under this Regulation. A thorough assessment of these criteria shall be based on modelling in order to capture the network and market dimensions of the European gas system. These dimensions are not limited to capacity and demand but are strongly influenced by supply availability, the location of the source and gas price. The assessment of the gas infrastructure in the TYNDP 2017 is done under the assumption of a well-functioning market (e.g. full implementation of Network Codes)

1) http://www.entsog.eu/public/uploads/files/publications/CBA/2015/INV0175-150213_Adapted_ESW-CBA_Methodology.pdf

# 2 Input data for the ESW-CBA

This chapter identifies the data to be used in the TYNDP-Step for the ESW-CBA methodology. More information and background for the data is available in the TYNDP report.

## 2.1 DIMENSION OF THE INPUT DATA

**The assessment in the TYNDP 2017 is done for the discrete years for the following dimensions:**

- Demand Scenarios
- Infrastructure levels

For combinations of scenarios and infrastructure levels, different temporal periods are investigated:

- The whole year consists of an average summer (AS) and an average winter (AW). During the assessment of the whole year, different supply configurations are investigated.
- The high demand situations are the peak day (DC) and the 2-week high demand case (14-day, 2W).

The single items are described more in detail in the next section.

### 2.1.1 Time Horizon for the input data

The set of input data for the Ten-Year Network Development Plan covers a 20-year horizon. The input data for the modelling is defined for each of the following five time snapshots: 2017, 2020, 2025, 2030 and 2035

### 2.1.2 Demand scenarios

The TYNDP 2017 contains 4 demand scenarios, out of which the data for the following three scenarios are selected as input data for the ESW-CBA[1)]:

- Blue Transition
- Green Evolution
- EU Green Revolution

For details see the demand chapter of the TYNDP report.

### 2.1.3 Temporal Period: Over-the-whole-year and high demand situations

In order to capture the seasonality of the gas market in the over-the-whole-year simulation, different levels of gas demand are considered as follows:

- Average Summer day: Summer is defined in TYNDP 2017 as the 7 month storage injection period (April to October, 214 days). Average summer demand is calculated using a factor per country applied to the yearly average demand.
- Average Winter day: Winter is defined in TYNDP 2017 as the 5 month storage withdrawal period (November to March, 151 days). Average winter demand is calculated using a factor per country applied to the yearly average demand.

1) The Slow Progression scenario is not modelled

**Yearly demand**
**=**
**365 * Yearly average demand**
**=**
**214 * Storage injection period average demand + 151 * Storage withdrawal period average demand**

The different duration of the season follows the actual observed storage withdrawal and injection periods in order to improve the modelling results for the storages.

In order to  capture special situation occurring with a lower statistical probability for which the gas infrastructure is also designed the following high demand situations are considered:

- 2-week high demand case (2W, 14 day uniform risk): Maximum aggregation of gas demand reached over 14 consecutive days once every twenty years in each country to capture the influence of a long cold spell on supply and especially on storage. The 14 days high demand period takes place based on the modelled situation from the over-the-whole-year simulation and is modelled starting on 15 February (after day 106 of storage withdrawal period).
- 1-day Design Case (DC, Peak): Maximum level of gas demand used for the design of the network in each country to capture maximum transported energy and ensure consistency with national regulatory frameworks. The peak day takes place based on the modelled situation from the over-the-whole-year simulation and is modelled on 31 January (after day 91 of storage withdrawal period).

### 2.1.4 Infrastructure levels

The assessment of the European gas system is performed under a number of Infrastructure levels.

The assessment of the European gas system under the PCI 2nd list infrastructure level is used separately only within the TYNDP-Step to measure the benefits from a full implementation of the latest PCI list. The assessment of the European gas system under the low infrastructure level leads primarily to the identification of investment gaps.

The TYNDP 2017 assesses 4 different infrastructure levels:

- Low
- Advanced
- PCI 2nd list
- High

The different infrastructure levels are based on the existing infrastructure, being defined as the firm capacity available on yearly basis as of 1st January 2016, and the aggregation of the project data for all the projects in each infrastructure level.

Details about the infrastructure level are described in the Infrastructure chapter of the TYNDP report.

### 2.1.5 Supply Configuration[1]

The ESW-CBA contains a balanced view plus a maximisation and a minimisation for each import source (Russia, Norway, Algeria, Libya, Azerbaijan and LNG) - in total 13 supply mixes – plus the import price spread configuration.

1) The terms Supply Configuration / Supply Mix replaced the term Price Configuration as it was used in previous documents. Equally, it is referred to as the minimisation/maximisation of the source, instead of the price of the source being expensive/cheap. While the concept from the approved CBA methodology is still the same, it was an outcome of the stakeholder engagement process that this terminology reflects better the intention of the concept.

## 2.2 INPUT DATA ITEMS

The following table identifies every data item used as part of the implementation of the TYNDP-Step of the ESW-CBA methodology.

The following table identifies each input data item for demand, prices, supplies and gas network data used within the ESW-CBA methodology:

**LIST OF INPUT DATA ITEMS**

| TYPE | DATA ITEM | LEVEL OF DEFINITION | DEPENDENCE |
|---|---|---|---|
| Total Gas demand | Yearly | Zone | Scenario, time horizon* |
| | Average Summer Day | | |
| | Average Winter Day | | |
| | 2-week high demand | | |
| | 1-day Design Case | | |
| Supply price curve | Volumes at start of price curve | Source | Scenario, supply configuration, time horizon |
| | Price at start of price curve | | |
| | Volumes at end of price curve | | |
| | Price at end of price curve | | |
| Import Price | Maximum for Design Case | Inter-Zone connections | – |
| Gas supply potential from import sources | Minimum for Design Case | Source | Time horizon |
| | Maximum for 2-Week Case | | |
| | Minimum for 2-Week Case | | |
| | Maximum for Summer | | |
| | Minimum for Summer | | |
| | Maximum for Winter | | |
| | Minimum for Winter | | |
| | Minimum yearly | | |
| Existing Infrastructures (capacity) | Transmission (after Lesser-of-rule) | Inter-Zone connections, Zones | – |
| | UGS (Lesser-of-rule with transmission capacities, withdrawal and injection curves) | | |
| | LNG Terminal (Lesser-of-rule with transmission capacities, tank flexibilities) | | |
| Flow constraints | Minimum and maximum flows | Supply connections, Inter-Zone connection | Time horizon |
| Route Disruption | Disruption Case definitions and applicability | Inter-Zone connections, Zones | – |
| General and technical | Gas and $CO_2$ prices, Value of Lost Load | global | Scenario, time horizon |
| | Capacity increment | Project | |
| | Expected commissioning date | | |
| | FID status | | |
| | Advanced Status | | |
| | PCI status according to the 2015 selection | | |

* Gasification demand is also dependent on the infrastructure levels (See Annex C1 Country Specifics)

**Table 2.1:** List of input data items

## 2.2.1 Total gas demand

The total gas demand is comprised of the final demand (Industrial, Residential & Commercial and Transport) and the gas demand for power generation. The evolution of the total gas demand in areas with existing gas demand only depends on the scenario.

For gas demand in new consumption areas, the gas demand depends on the infrastructure connecting this area to gas supply.

In addition to the demand within the geographical scope of the TYNDP, exports have also been considered.

Details on the gas demand can be found in the demand chapter of the TYNDP report and in Annex C.

## 2.2.2 Supply Price Curve

Within the modelling tool, each supply source is described as a supply curve reflecting the supply potential and the gas price in the respective scenario for the given year. The curve is built on:

- The yearly average price of gas as defined in each scenario
- The Supply potential of each source

The next figure illustrates the construction of the curve of a given source on a given year:

For all price curves, the price difference between the starting point of the price curve and the maximum yearly supply source potential is 2€/MWh, with the Reference gas price being in the middle. Each price curve is starting at the same relative point, which incentivises a balances use of the different import sources. Nevertheless, each supply is still required to stay within the supply potential range defined for each source (between Minimum and Maximum).

For the purpose of maximisation/minimisation of supply from sources in the different supply configurations, the price of the source is lowered/raised by 5€/MWh.

A specific curve has been defined for the European indigenous production (conventional, shale gas and biogas). The curve is set as a flat line that is below the cheapest source, which is 7€/MWh below the Reference price

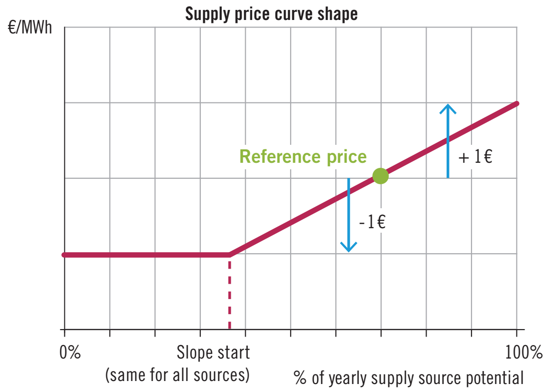



**Figure 2.1:** Supply curve

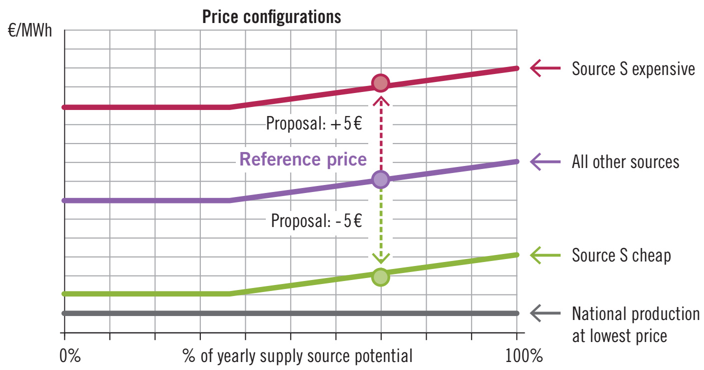



**Figure 2.2:** Price curves in price configurations

### 2.2.3 Price Spread

The price spread is used for the assessment within the import price spread configuration only. It consists of a price spread per import route based on historically observed information.

### 2.2.4 Gas supply potential from import sources

For each climatic case and each import supply sources, a range is defined as:

- **Average Summer day:**
  - **Minimum:** the Minimum Supply Potential as defined in the TYNDP
  - **Maximum**: the Maximum Supply Potential as defined in the TYNDP
- **Average Winter day:**
  - **Minimum:** the Minimum Supply Potential as defined in the TYNDP
  - **Maximum:** 110% of the Maximum Supply Potential as defined in the TYNDP
- **14-day Uniform-Risk for each import source:**
  - **Minimum:** the Minimum Supply Potential as defined in the TYNDP
  - **Maximum for each pipe import source:** 110% of the Maximum Supply potential as defined in the TYNDP.
  - **Maximum for LNG:**
    - Flexibility from the LNG tanks can be used as additional LNG supply for both weeks.
    - In the first week the global LNG flows are limited to the level observed in Average Winter from the previous modelling of the whole year.
    - In the second week additional cargos can arrive allowing the supply to reach the daily maximum supply potential of Average Winter (110% of the maximum LNG Supply potential as defined in the TYNDP).
- 1-day Design Case for each import source:
  - **Minimum:** the Minimum Supply potential as defined in the TYNDP
  - **Maximum for pipe imports:** 110% of the Maximum Supply potential as defined in the TYNDP.
  - **Maximum for LNG:** the Supply potential plus the tank flexibility should allow all the LNG terminals to reach their send-out capacity.

**The actual use of supply is a result of the model taking into account the minimum and maximum constraints.**

Whilst the working gas volume of the storages starts and ends with the same level (30%) for the whole year, this can change for high demand situations. For high demand situations, the starting level for the working gas volume is determined by the whole year simulation. This working gas level, the withdrawal capacities and the withdrawal curves define the constraints for the storage use during high demand situations. The actual use of storages is a result of the model taking into account these constraints.

### 2.2.5 Existing Infrastructure (capacity, storage volumes)

The existing transmission infrastructure is defined as the firm capacities available on yearly basis as of 1st January 2016. In addition to the existing transmission infrastructure, the existing LNG and storage infrastructure is considered.

The transmission infrastructure is defined by the technical capacities between countries. For this, the technical capacities at interconnection points between these countries are aggregated after the application of the lesser-of-rule.

LNG infrastructure is defined by the regasification capacity along the average year and during high demand situations. The LNG tank volumes have characteristics; a flexibility factor defines the share of the tank volume that can be expected to be available during high demand situations. This flexibility has been defined by GLE.

In addition to the working gas volumes and the withdrawal and injection capacities, withdrawal and injection curves for storages are taken into account. These curves define the abilities of storages to withdraw or inject gas depending on the fill level. The curves for the TYNDP 2017 have been defined in cooperation with GIE.

### 2.2.6 Flow constraints

TYNDP 2017 takes into account minimum flow requirements from the Netherlands to Germany and Belgium and from Belgium to France until 2025 in all scenarios. These minimum flow requirements represent physical requirements from the L-gas areas.

In addition to this minimum imports from Turkey to Greece are considered until 2020[1].

### 2.2.7 Route Disruption

As in previous TYNDP, the methodology considers major supply stresses against which the European gas system is assessed. Depending on the source one or two potential complete disruption events have been defined:

- Russian transit through Ukraine
- Russian transit through Belarus
- Langeled pipeline between Norway and UK
- Franpipe pipeline between Norway and France
- Transmed pipeline between Algeria and Italy
- MEG pipeline between Algeria and Spain (including supply to Portugal)
- TANAP pipeline between Azerbaijan and Greece
- "Greenstream" pipeline between Libya and Italy

No specific disruption event is considered for LNG given the global dimension of the market preventing large scale effect of a political or technical disruption along the gas chain.

A disruption case is represented in the ESW-CBA by the reduction of the available capacity of the existing infrastructure.

### 2.2.8 General and technical

The general and technical information covers the price information for gas depending on the year and scenario as well as project-specific data like the capacity increment, the expected commissioning date, the FID status, the advanced status and the PCI status according to the 2015 selection. This information was submitted by the project promoters during the project data collection and is used to aggregate the different infrastructure levels based on the individual projects. The Value of Lost Load (VoLL) quantifies the monetary impact of a disruption in the modelling. A standardised approach with a value of 600 EUR/MWh is used in the TYNDP 2017.

1) http://www.depa.gr/content/article/002003006/160.html

# 3 Network and market modelling

ENTSOG has developed a modelling approach since 2010, based on a specific structure facing the need to consider simultaneously network and market dimensions. The network model represents the gas market within the geographical scope of the TYNDP. Arcs for the network modelling, including the relevant capacities for each infrastructure level can be found in ANNEX D.

## Entry/Exit model

The geographical scope is the European Union and other countries part of the European Economic Area. In the following, the term "Zone" will be used generally to refer to a country. In some instances it refers to a balancing zone.

The basic block of the topology is the balancing Zone (or Zone) at which level demand and supply shall be balanced. The Zones are connected through arcs representing the sum of the capacity of all Interconnection Points between two same Zones (after application of the "lesser of" rule). Interconnectors with specific regime (e.g. BBL or Gazelle) are represented by Zones with no attached demand.

In order to avoid extreme flow patterns (e.g. most of the arcs empty or fully used) where it is not necessary to balance demand and supply, each arc is subdivided into several arcs, each one representing an equivalent percentage of the total capacity between the two Zones with an increasing cost weight.

## Focus on a Zone

The supply and demand balance in a Zone depends on the flow coming from other Zones or direct imports from a supply source. Gas may also come from national production, underground storage and LNG facilities connected to the Zone. The sum of all these entering flows has to match the demand of the Zone, plus the need for injection and the exit flows to adjacent Zones.

In case the balance is not possible, a disruption of demand is used a last resort virtual supply. This approach enables an efficient analysis of the disrupted demand.

## Objective function

The primary objective of the modelling is to define a feasible flow pattern to balance supply and demand for every node, using the available system capacities defined by the arcs. In addition, the use of price assumptions in the input data supports the definition of a feasible flow pattern minimising the objective function[1)] representing costs to be borne by the European society.

This optimum differs from national optimums which are potentially not reached through the same flow pattern.

The minimisation of the objective function is based on the concept of marginal price of a node. It is defined as the cost of the last unit of energy used to balance the demand of that node.

The overall objective function used in the methodology is the following:

*Commodity Cost + Weight of disruption + Weight of infrastructure used -> Min*

with

*Commodity Cost = Cost of gas supply*

*Weight of infrastructure used = Weight of transmission + Weight of storage + Weight of regasification*

*Weight of disruption = Weight of disrupted demand*

Each component is defined as the sum for each arc of the flow through the arc multiplied by its unitary cost or weight.

$$Cost\ of\ gas\ supply = \sum_{S}^{Gas\ sources} \sum_{n}^{Multiple\ arcs\ source\ S} Flow_n \times Cost_n$$

Where $Cost_n$ is the price per unit of gas supply as resulting from the supply price curves in the input data.

$$Weight\ of\ transmission = \sum_{t}^{Arc\ between\ Zones} Flow_t \times Weight_t$$

$$Weight\ of\ storage = \sum_{w}^{Arc\ from\ storage} Flow_w \times Weight_w + \sum_{i}^{Arc\ to\ storage} Flow_i \times Weight_i$$

$$Weight\ of\ regasification = \sum_{l}^{Arc\ from\ LNG\ terminal} Flow_l \times Weight_l$$

$$Weight\ of\ disrupted\ demand = \sum_{DD}^{Arc\ from\ disrupted\ demand\ arcs} Flow_{DD} \times Weight_{DD}$$

The infrastructure weights are used to model market behaviour when defining flow pattern (e.g. ensuring a reasonable use of storage to cover winter demand). Nevertheless, the high or low use of gas infrastructures influences the cost for society only slightly (it is mostly an internal transfer between users and operators). Therefore these weights are ignored when monetising benefits.

1) Use of the Jensen solver as developed by Paul Jensen for the Texas University in Austin (https://www.me.utexas.edu/~jensen/ORMM/index.html)

## Storage target

For each simulation, a target storage level is used, and is set equal to the initial level.

For the normal year simulation (summer + winter), this target is mandatory. The goal is to evaluate a normal situation in a sustainable running mode, and therefore the storage use must be neutral over the course of the year.

For the Peak and 2 Week cold Spell simulations, the target level is not mandatory, meaning that storage working gas volume can be used as much as needed (the limitation being on the withdraw capacity).

## Evaluation of the social welfare

All benefits coming along the gas chain including suppliers, infrastructure operators and end-consumers are included in the social welfare.

Based on economic theory, the European social welfare is defined as the yellow area between the supply and demand curves. The change in social welfare induced by a project is then additional red stripped area resulting from the change of the supply curve where there is a better access to cheap source (additional red part at the bottom of the curve) as shown in following figures (also defining the marginal price as the intersection of the two curves):

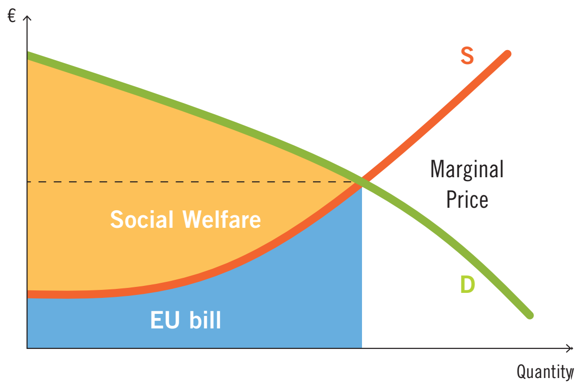



**Figure 3.4a:** Social Welfare before the project

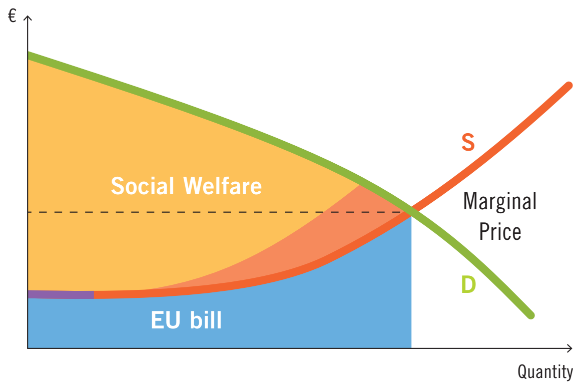



**Figure 3.4b:** Social Welfare after the project

Applying this approach to the ESW-CBA modelling approach with an inelastic demand, the change in Social Welfare is equivalent to the change in the gas bill as shown in the following figures:

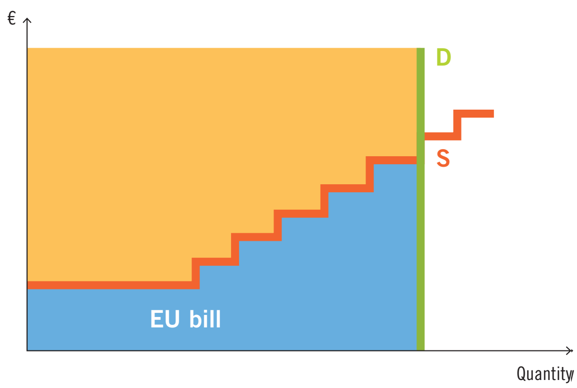



**Figure 3.5a:** Social Welfare with inelastic demand before the project

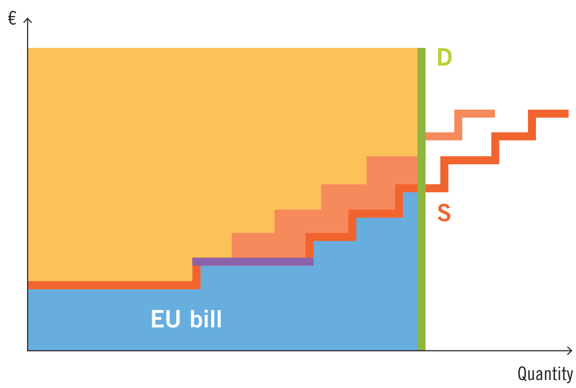



**Figure 3.4b:** Social Welfare with inelastic demand after the project

## List of cases to be modelled

The modelling approach previously described is to be applied to all the cases supporting the calculation of indicators and monetisation of gas supply.

The following table defines the combination of the climatic cases with the supply mix and the route disruption that is modelled in the TYNDP 2017 and their purposes. These combinations are modelled for each time snapshot, infrastructure level and scenario.

**LIST OF CASES TO BE MODELLED**

| CLIMATIC CASE | SUPPLY CONFIGURATION | ROUTE DISRUPTION | PURPOSE |
|---|---|---|---|
| WHOLE YEAR* TOGETHER | Supply Min/Max configurations | No | Monetisation |
| | Price Spread configuration | No | Monetisation |
| | Defined under each indicator | No | Indicators |
| WHOLE YEAR* WITH RESULTS PER CLIMATIC CASE | Supply Min/Max configurations | No | Marginal Price |
| DESIGN CASE & 14-DAY UNIFORM RISK | Balanced | No | Remaining Flexibility<br>Disrupted Demand |
| | | Disruptions | Remaining Flexibility<br>Disrupted Demand |

* Consisting of a summer and a winter period

**Table 3.1:** List of cases to be modelled

## Output of the modelling

The output of the modelling consists of the flows for each supply source, the results for the indicators and monetisation. It is shown in Annex E of the TYNDP 2017.

# 4 Indicators

A set of indicators has been defined in order to cover all specific criteria of the Regulation and to ensure comparability of project assessments.

According to the way the indicators are calculated, two types can be distinguished:

- Capacity-based indicators which reflect the direct impact of infrastructures on a given country as their formulas are limited to capacity and demand of a country.
- Modelling-based indicators, which reflect in addition the indirect cross-border impact of infrastructure as their formulas also consider the availability and nature of flows resulting from the modelling of the European gas system.

The next table defines the list of indicators to be calculated per Zone or country as part of the TYNDP for each for each time snapshot, infrastructure level and scenario:

**LIST OF INDICATORS**

| | INDICATOR | CLIMATIC CASE | WITHOUT ROUTE DISRUPTION | WITH ROUTE DISRUPTION |
|---|---|---|---|---|
| **CAPACITY-BASED** | N-1 | DC | N/A | N/A |
| | Import Route Diversication | N/A | N/A | N/A |
| **MODELLED-BASED** | Remaining Flexibility | DC & 2W | × | × |
| | Disrupted Demand | DC & 2W | × | × |
| | Cooperative Supply Source Dependence | Whole year* | × | |
| | Uncooperative Supply Source Dependence | Whole year* | × | |
| | Supply Source Price Diversification | Whole year* | × | |
| | Supply Source Price Dependence | Whole year* | × | |
| | Price Convergence | Whole year | × | |

* Consisting of a summer and a winter period

**Table 4.1:** List of indicators

## 4.1 CAPACITY-BASED INDICATORS

### 4.1.1 Import Route Diversification (IRD)

This indicator measures the diversification of paths that gas can flow through to reach a Balancing Zone in an EU country, or a non-EU country that is part of the TYNDP perimeter. Together with the Supply Source Price Diversification, it provides a proxy to the assessment of counterparty diversification.

$$\sum_{l}^{X\ border} \left(\sum_{k}^{IP} \%\ IP_k Xborder_l\right)^2 + \sum_{j}^{source} \left(\sum_{i}^{IP} \%\ IP_i from\ source_j\right)^2 + \sum_{m} (\%\ LNG\ terminal_m)^2$$

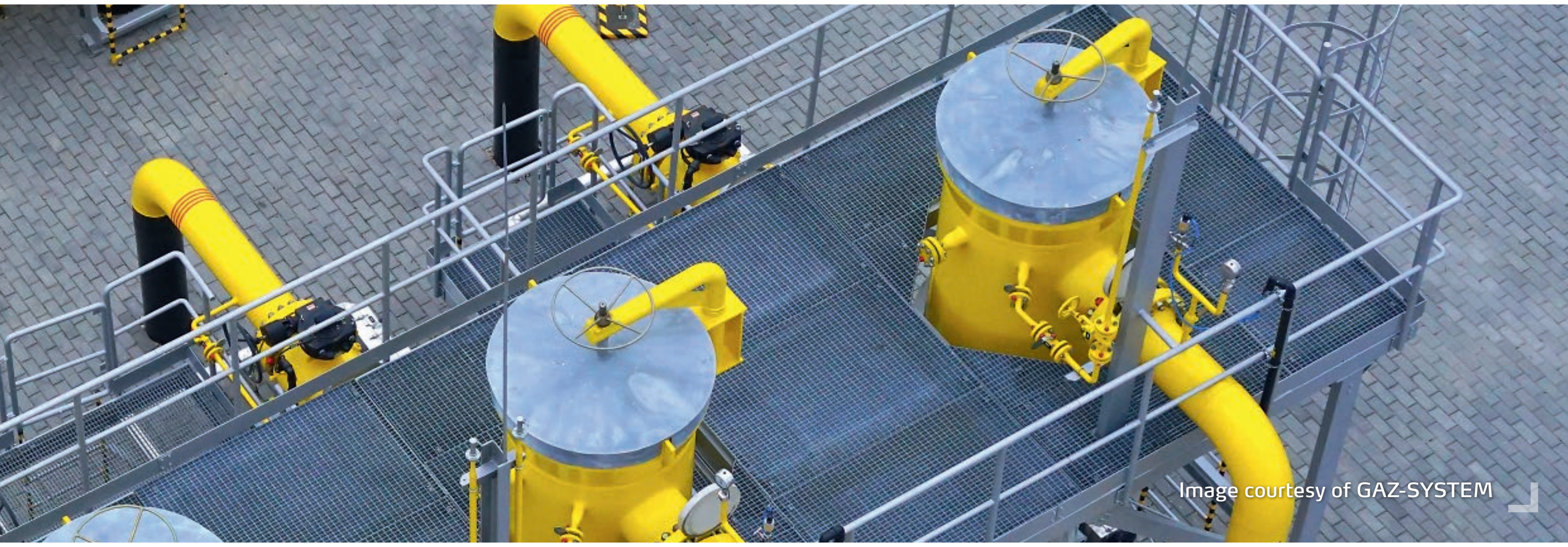
The below shares are calculated in comparison with the total entry firm technical capacity into the Balancing Zone from each adjacent Balancing Zone or country part of the TYNDP perimeter, from each import source, and from each LNG terminal:

- **$IP_k$ $Xborder_l$:** the share of the firm technical capacity of the interconnection point $IP_k$ belonging to the border with the Balancing Zone or the non-EU country part of the TYNDP perimeter
- **$IP_i$ from $source_j$:** the share of the firm technical capacity of the import point $IP_i$ coming directly from the source *j* (e.g. offshore pipeline).
- **LNG $terminal_m$:** the share of the firm technical send-out capacity of the LNG terminal *m*

For Interconnection Points between Balancing Zones and/or non-EU countries part of the TYNDP perimeter, capacity is first aggregated at Balancing Zone or country level[1)], as those physical points are likely to largely depend on common infrastructures. LNG terminals are considered as completely independent infrastructures.

The lower the value, the better the diversification is.

1) In France, FRs and FRt are treated as one zone (TRS). The results for this zone are relevant for both FRs and FRt



### 4.1.2 N-1 for ESW-CBA (N-1)

Under REG (EC) 994/2010, this indicator is calculated by the Competent Authority on a two year range. The use of such an indicator within the ESW-CBA will be based on the same formula, using the ESW-CBA data set:

$$N-1=\frac{IP+NP+UGS+LNG-I_m}{Dmax}*100$$

The indicator is calculated for all Infrastructure Levels considered in the respective TYNDP, as well as for a set of Global Scenarios defined within the TYNDP. It is calculated at country level, where:

- **IP:** technical capacity of entry points *(GWh/d),* other than production, storage and LNG facilities covered by *NP*, *UGS* and *LNG*, means the sum of technical capacity of all entry points capable of supplying gas to the transmission system(s) of the calculated country. The entry points which are considered are:
  - Cross-Border Import Points from non-EU countries to EU countries
  - Cross-Border Export Points from EU countries to non-EU countries part of the TYNDP perimeter
  - Cross-Border Points between non-EU countries and non-EU-countries part of the TYNDP perimeter
  - Cross-Border Points between EU countries
  - In-Country Points between two distinct Balancing Zones
- **NP:** maximal technical production capability *(GWh/d)* means the sum of the maximal technical daily production capability of all gas production facilities which can be delivered to the entry points of the transmission system(s) in the calculated country; taking into account their respective physical characteristics.
- **UGS:** maximal storage technical deliverability *(GWh/d)* means the sum of the maximal technical daily withdrawal capacity of all storage facilities which can be delivered to the entry points of the transmission system(s) in the calculated country, taking into account their respective physical characteristics.
- **LNG:** maximal technical LNG facility capacity *(GWh/d)* means the sum of the maximal technical send-out capacities at all LNG facilities in the calculated country, taking into account critical elements like offloading, ancillary services, temporary storage and re-gasification of LNG as well as technical send-out capacity to the system.
- $\mathbf{I_m}$ is the technical capacity of the single largest gas infrastructure *(GWh/d)*. The single largest gas infrastructure is the largest gas import infrastructure covered either by IP or by LNG that directly or indirectly contributes to the supply of gas to the transmission system(s) of the calculated country. The application of the "lesser of" rule and the analysis on a 20-year time horizon may result in a different infrastructure than the one identified by Competent Authorities as part of the Risk Assessment under Regulation (EC) 994/2010.
- $\mathbf{D_{max}}$ is the total daily gas demand *(GWh/d)* of the calculated area during a day of exceptionally high gas demand, as defined by the 1-day Design Case (DC, Peak) high demand situation.

Only in case that a regional formula has been defined and agreed by the Competent Authorities of the corresponding region, the calculation shall be adjusted using the same ESW-CBA data set.

The higher the indicator is, the better the resilience.

## 4.2 MODELLING-BASED INDICATORS

In the following description, the term "Zone" will generally be used to refer to a country. In some instances it refers to a balancing zone. The relevant Zones can be found in the annex E where the respective indicator is shown.

### 4.2.1 Remaining Flexibility (RF)

This indicator measures the resilience of a Zone as the additional share of demand each country is able to cover before no longer being able to fulfil its demand without creating new demand curtailment in other Zones. The value of the indicator is set as the possible increase in demand of the Zone before an infrastructure or supply limitation is reached somewhere in the European gas system.

This indicator will be calculated under 1-day Design Case and 14-day Uniform Risk situations with and without supply stress.

The Remaining Flexibility of the Zone Z is calculated as follows (steps 2 and 3 are repeated independently for each Zone):

1. Modelling of the European gas system under a given climatic case
2. Increase of the demand of the Zone Z by 100 %
3. Modelling of the European gas system in this new case

The Remaining Flexibility of the considered Zone is defined as 100 % minus the percentage of disruption of the additional demand.

The higher the value, the better the resilience is. A zero value would indicate that the Zone is not able to fulfil its demand and a 100 % value will indicate it is possible to supply a demand multiplied by a factor two.

### 4.2.2 Disrupted Demand (DD) and Disrupted Rate (DR)

The amount of disrupted demand for a given Zone is provided:

- In energy (DD)
- As relative share/percentage (DR)

This amount is calculated in a Cooperative mode, that is, under the flow pattern maximising the spreading of the disrupted demand (in order to reduce the relative impact on each Zone). This means that, if possible, all the Zones will share the same disrupted rate

### 4.2.3 Uncooperative Supply Source Dependence (USSD)

This indicator identifies Zones whose physical supply and demand balance depends strongly on a single supply source when each Zone tries to minimise its own dependence (the Zones closest to the considered source are likely to be the more dependent).

It is calculated for each Zone vis-à-vis each source under a whole year as the succession of an Average Summer and an Average Winter.

The Supply Source Dependence of all Zones to source S is calculated as follows (steps 1 to 4 are repeated for each source):

1. The availability of source S is set down to zero
2. The availability of the other sources is not changed
3. The cost of disruption is set flat and at the same level for each Zone
4. Modelling of the European gas system under the whole year

The Uncooperative Supply Source Dependence of the Zone Z to the source S is defined as:

$$USSD = \frac{DD^Z}{Demand^Z}$$

Where:

$DD^Z$ is the disrupted total gas demand

$Demand^Z$ is the total gas demand

The lower the value of USSD is, the lower the dependence.

## 4.2.4 Cooperative Supply Source Dependence (CSSD)

This indicator identifies Zones where the physical supply and demand balance depends strongly on a single supply source, when all Zones together try to minimise the shared relative impact (the flow pattern resulting from modelling will spread the dependence as wide as possible in order to mitigate as far as possible the dependence of the most dependent Zones).

It is calculated for each Zone vis-à-vis each source under a whole year as the succession of an Average Summer and an Average Winter.

The Supply Source Dependence of all Zones to source S is calculated as follow (steps 1 to 4 are repeated for each source):

1. The availability of source S is set down to zero
2. The availability of the other sources is not changed
3. The cost of disruption is escalating by step of 10 % of demand with the same price steps for each Zone
4. Modelling of the European gas system under the whole year

The Cooperative Supply Source Dependence of the Zone Z to the source S is defined as:

$$CSSD^Z = \frac{DD^Z}{Demand^Z}$$

Where:

$DD^Z$ is the disrupted total gas demand

$Demand^Z$ is the total gas demand

The lower the value of CSSD is, the lower the dependence.

### 4.2.5 Supply Source Price Diversification (SSPDi)

This indicator measures the ability of each Zone to take benefits from an alternative decrease of the price of each supply source (such ability does not always mean that the Zone has a physical access to the source).

For the calculation of this indicator:

- the minimum supply constraint is removed for each supply source
- the maximum supply constraint is removed for the studied supply source

It is calculated for each Zone under a whole year as the succession of an Average Summer and Average Winter.

The Supply Source Price Diversification of all Zones to source S is calculated as follows:

**Step 1:** The maximum supply constraint for source S is removed.

**Step 2:** All sources have their price curves set flat at the same price (including national production).

**Step 3:** The price level of source S is decreased by 20 % ensuring that source S is maximised.

**Step 4:** The marginal price curves are computed for each Zone (see description below).

**Step 5:** The price level of source S is further decreased by 10 % (from 80 % to 72 %).

**Step 6:** The marginal price curves are computed again for each Zone (see description below)

## Marginal price curve

For a given Zone, the marginal price curve mentioned in step 4 and step 6 is a set of marginal prices ($MP_k$) that are determined for successive simulations with different percentage of demands.

The process for the ($k^{th}$) simulation is the following:

- Consider the original demand for the given scenario
- For each Zone, take $x_k$ % of the demand, where the $x_k$ values are ranging from 0.1 % to 99.9 %.
- Reduce the lower constraints (minimum supply constraints) to $x_k$ % of their original values.
- Run a simulation, and for each Zone retrieve the resulting marginal price $MP_k$).

### SSPDi

For each demand range [k,k+1], an average drop of marginal price is computed (except for the two extreme ranges, the first and last 0.1%, where only one marginal price is used):

- $\text{MP change}_{[k,k+1]} = \frac{1}{2} * [\text{Abs}\left(\frac{\text{MP}_{k+1\ \text{Step6}}}{\text{MP}_{k+1\ \text{Step4}}} - 1\right) + \text{Abs}\left(\frac{\text{MP}_{k\ \text{Step6}}}{\text{MP}_{k\ \text{Step4}}} - 1\right)]$
- $Demand\ range\ percentage_{[k,k+1]} = x_{k+1} - x_k$

$$\boldsymbol{SSPDi} = \frac{\mathbf{1}}{\mathbf{10\%}} * \sum_{k} \left(\boldsymbol{MP\ change}_{[k,k+1]}\right) * \left(\boldsymbol{Demand\ range\ percentage}_{[k,k+1]}\right)$$

The bigger the SSPDi, the better the access from a price perspective.

Finally the diversification of a Zone is characterised by both:

- the number of sources for which the SSPDi is high
- the magnitude of a given SSPDi.

## 4.2.6 Supply Source Price Dependence (SSPDe)

This indicator measures the price exposure of each Zone to the alternative increase of the price of each supply source.

The process is exactly the same as for the SSPDi. The only difference is that, instead of decreasing the flat price by 20% and 10% in step 3 and 5, it is rather increased by 20% and 10%.

The bigger the SSPDe, the higher the exposure from a price perspective.

Finally the dependence of a Zone is characterised by both:

- the number of sources for which the SSPDe is high for the considered Zone
- the magnitude of a given SSPDe.

## 4.2.7 Marginal Price

For each climatic case, the marginal price of gas supply of a Zone is a direct output of the optimisation.

It is calculated for each Zone under a whole year as the succession of an Average Summer and an Average Winter, resulting potentially in two different marginal prices (one for summer and one for winter).

The lower the difference between the marginal prices of two Zones, the better the Price Convergence.

# 5 Import Price Spread Configuration

## Objective

The import price spread configuration investigates the impact of different supply prices for different routes of the same supply. It intends to model projects' impact on monopolistic behaviour and value the associated benefits of increased competition.

## Price Spreads input

Based on transparent information, different import price spreads are set per route, at the border of EU. These spreads are measured against a reference Zone, for which the import spread has been set at 0. For the TYNDP 2017, the reference Zone is GASPOOL (noted hereafter DEg).

## Initial situation

The configuration starts from an initial situation, where these price spreads inputs are used. The modelling of the initial situation will provide the "initial import flows".

## Following years

After the initial year, the situation will evolve depending on demand and infrastructure.

Assumptions retained to model the behaviour of the initially monopolistic supplier:

- The supplier will maintain its import route pricing policy, although losing volumes, up to the point of losing **20 %** of the volume delivered to the import point (the "initial import flows").
- Beyond this point, the supplier will align its price to the competing source.
- The supplier adopts a **volume priority strategy**.

In order to avoid impossible constraints, an exception is made for countries where the demand is decreasing below the 80 % threshold along the years. For the TYNDP 2017, this threshold is changed to 80 % of their lowest import demand, that is, demand minus national production (instead of 80 % of the initial import flows). The lower boundary on the threshold is set to 10 % of the lowest demand along the years and scenarios.

## Price curves

For the TYNDP 2017, a balanced approach has been used where all supply curves (upstream of the import route) are at the same level.

## Outputs

Several outputs can measure the evolution of the situation:

- The EU bill
- The marginal price for each Zone (linked to consumer surplus)
- The monetisation per Zone, only measured as a difference between two infrastructure levels.

# 6 Monetisation

## 6.1 MONETISATION AT EU LEVEL

The monetary analysis is based on the calculation of costs for Europe. The EU bill is also the function that the model tries to minimise, ensuring consistency between the results provided and the target of improving the situation for Europe as a whole.

In TYNDP, results of the monetisation illustrate the potential evolution of the gas bill from one scenario to the others.

## 6.2 MONETISATION OF DISRUPTION

The disruption is monetised ex-post, based on the disrupted quantity (demand curtailment) resulting from the modelling and the Value of Lost Load form the input data (VoLL).

$$\text{Monetisation of Disruption} = \text{Disrupted Quantity} * \text{VoLL}$$

Image courtesy of Gasum

## 6.3 MONETISATION PER ZONE – MIN/MAX SUPPLY PRICE CONFIGURATIONS

The monetisation per Zone for the min/max supply price configuration is produced relatively to the "Balanced" configuration.

### Basic principle

In a supply maximisation configuration (supply cheap) the EU bill difference is split per Zone based on the SSPDi weighted by demand.

In a supply minimisation configuration (supply expensive) the EU bill difference is split per Zone based on the CSSD weighted by demand.[1)]

### Detailed process

In the following, "indicator" will mean either CSSD or SSPDi, depending on the configuration. The word "Standardised Spread" will mean the value by which the standardised price curves were moved in the min/max supply price configurations. In the TYNDP 2017, the Standardised Spread is 5€/MWh.

**Step 1: Allocation based on indicator*demand**

- For each Zone, compute indicator*demand (Labelled afterwards as "Zone Key Split 1")
- Compute the sum of the previous quantities (Labelled afterwards as "Total Key Split 1")
- For each Zone, compute the allocated bill difference

$$\text{Zone allocated bill difference} = \text{EU Bill Difference} * \frac{\text{Zone Key Split1}}{\text{Total Key Split1}}$$

- For each Zone, compute the equivalent spread in price

$$\text{Zone equivalent price spread} = \frac{\text{Zone allocated bill difference}}{\text{Zone demand}}$$

- For each Zone, compute the maximum allowed spread (Labelled afterwards as "Zone Max Spread")

$$\text{Zone Max Spread} = \text{indicator} * \text{Standardised Spread}$$

- For each Zone, compute the spread for Step1 (Labelled afterwards as "Zone Spread 1")

$$\text{Zone Spread 1} = \text{Minimum}(\text{Zone equivalent price spread}, \text{Zone Max Spread})$$

- For each Zone, compute the corrected allocated bill difference

$$\text{Zone bill difference Step1} = \text{ZoneSpread1} * \text{Demand}$$

- Compute the sum of the previous quantities (Labelled afterwards as "EU Bill Difference Allocated")
- Compute the unallocated part of the EUBill (Labelled afterwards as "EU Bill Difference Unallocated")

$$\text{EU Bill Difference Unallocated} = \text{EU Bill Difference} - \text{EU Bill Difference Allocated}$$

1) Out of the two supply dependence indicator, the CSSD has been chosen over the SSPDe because, even though they are highly correlated, the CSSD is more straightforward to apprehend by stakeholders.

**Step 2: Allocation of the unallocated part based on (1-indicator)*demand**

- For each Zone, compute (1-indicator)*demand (Labelled afterwards as "Zone Key Split 2")
- Compute the sum of the previous quantities (Labelled afterwards as "Total Key Split 2")
- For each Zone, compute the allocated bill difference

$$\text{Zone bill difference Step2} = \text{EU Bill Difference Unallocated} * \frac{\text{Zone Key Split2}}{\text{Total Key Split2}}$$

**Finally**

- For each Zone, compute the bill difference

$$\text{Zone bill difference} = \text{Zone bill difference Step1} + \text{Zone bill difference Step2}$$

Image courtesy of Gasunie

## 6.4 MONETISATION PER ZONE – PRICE SPREAD CONFIGURATION

The monetisation per Zone for price spread configuration is calculated for one infrastructure level relative to another.

### Basic principle

A split of the difference in the EU bill is calculated between what can be directly allocated, and what cannot. The unallocated part will be split based on the difference of marginal prices between the two configurations, weighted by the demand.

### Detailed process

In the following description, the term Δ(quantity) is used to design the difference in the values of a given quantity between two configurations (for instance LOW and ADVANCED).

$$\text{EU Bill Difference} = \Delta(\text{"Total EU Bill adjusted Price Spread"})$$

First the difference of the adjusted EU Bill is computed:

**Step 1: Allocation based on "Price Spread Adjustment Gain"**

In the modelling results, a quantity named "Price Spread Adjustment Gain" is available for each Zone. This quantity is computed ex-post. It is the amount by which the bill in the country would drop following an import price spread adjustment as a consequence of the import flow reaching the minimum flow threshold.

Any difference in the "Price Spread Adjustment Gain" can be allocated directly to the corresponding Zone.

- For each Zone, compute the directly allocated bill difference

$$\text{Zone direct allocation} = -\Delta(\text{Price Spread Adjustment Gain})$$

- Compute the sum of the previous quantities (Labelled afterwards as "EU Bill Difference Allocated")
- Compute the unallocated part of the EU Bill (Labelled afterwards as "EU Bill Difference Unallocated")

$$\begin{aligned}&\text{EU Bill Difference Unallocated}\\&\qquad = \text{EU Bill Difference} - \text{EU Bill Difference Allcoated}\end{aligned}$$

**Step 2: Allocation of the unallocated part based on the marginal prices**

- For each Zone, compute the maximum possible consumer surplus

$$\text{Zone Max Consumer Surplus} = \text{demand} * \Delta(\text{Zone marginal price})$$

- For each Zone, compute the key to allocate the remaining part of the EU Bill difference

$$\text{Zone Key Split} = \text{Zone Max Consumer Surplus} - \text{Zone direct allocation (Step1)}$$

- Compute the sum of the previous quantities (Labelled afterwards as "Total Key Split")
- For each Zone, compute the bill difference allocated indirectly

**Finally**

For each Zone, compute the bill difference

$$\text{Zone bill difference} = \text{Zone direct allocation} + \text{Zone indirect allocation}$$

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All Annexes are available as PDF or Excel-file on www.entsog.eu/publications/tyndp


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