METIS Technical Note T7

METIS Gas System Module Documentation

METIS Technical Notes
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Prepared by

Régis Bardet (Artelys)
Maxime Chammas (Artelys)
Laurent Fournié (Artelys)

Contact: metis.studies@artelys.com

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Directorate A — Energy Policy
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E-mail: ENER-METIS@ec.europa.eu

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European Commission
B-1049 Brussels

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1. INTRODUCTION

METIS is an on-going project[1] initiated by DG ENER for the development of an energy modelling software, with the aim to further support DG ENER's evidence-based policy making, especially in the areas of electricity and gas. The software is developed by Artelys with the support of IAEW (RWTH Aachen University), ConGas and Frontier Economics as part of Horizons 2020 and is closely followed by DG ENER. Two versions have been already delivered at the DG ENER premises.

The intention is to provide DG ENER with an in-house tool that can quickly provide insights and robust answers to complex economic and energy related questions, focusing on the short-term operation of the energy system and markets. METIS was used, along with PRIMES, in the impact assessment of the Market Design Initiative.

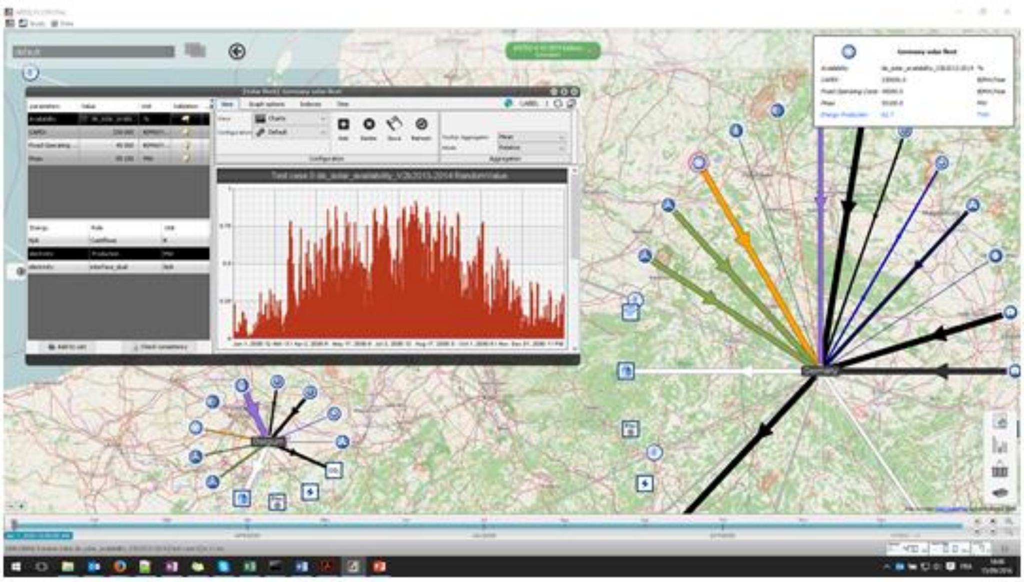

Figure 1: METIS user interface screen

The Gas System Module of METIS has been designed to address multiple gas systems problematics, following a welfare-maximization principle. It allows the analysis of the European gas systems' dynamics, by providing production plans, gas flows, loss of load, or other standard indicators detailed further in the document.

Such a modelling tool can be used to conduct different types of studies or quantitative analysis on gas systems, among which:

- Gas security of supply analysis
- Supply and price dependence analysis
- Study of the impact of infrastructure projects on security of supply

The present document is organised as follows:

- **Section 2** is dedicated to the specification of the asset models and objective function of the optimisation problem solved to obtain the cost-minimizing behaviour of the system,
- **Section 3** describes which dataset are embedded by default in METIS to perform gas system studies,

[1] http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf

- **Section 4** describes some of the main outputs and key performance indicators METIS provides and some of the features of the interface to display them.

Note that METIS also embeds a Power System Module (enabling the modelling of the European power system) and a Power Market Module (containing models for European intra-day and balancing markets) which have their own specific documentation. A demand and a gas market module are also currently in development (as of May 15, 2017).

2. GENERAL MODELLING EQUATIONS

In METIS, the gas system is represented by a network in which each node stands for a couple (geographical zone[2], energy). A geographical zone can be linked to other zones with transmissions (e.g. pipelines to exchange gas). Several nodes can be attached to the same geographical zone if they represent different "energies". In the gas system module, the following energies can be found: gas (representing natural gas), LNG and CO2. At each node are attached assets that represent all consumption and production of energy at this node. The model aims at minimizing the overall cost of the system to maintain a supply/demand equilibrium at each node.

The following section describe the list of assets included in the model, the objective function of the optimisation problem and the generic model for assets.

2.1. ASSET LIBRARY

METIS gas system module contains a library of assets for production, consumption and transmissions that can be attached to each node of the network.

The following assets are included:

- Gas consumption: national demand of natural gas,
- Gas production: indigenous production of natural gas,
- Gas storage: storage facilities for gas,
- LNG terminal: gasification terminals, receiving and transforming LNG into natural gas,
- LNG imports: imports of LNG sent to LNG terminals,
- LNG exports: liquefaction train, liquefying natural gas and exporting LNG,
- Gas imports: imports of natural gas from non-modelled countries through pipelines,
- Gas exports: exports of natural gas to non-modelled countries through pipelines,
- Pipelines: gas transmissions between modelled zones,
- CO_2 emissions: CO_2 emissions due to the consumption of natural gas, associated with a CO_2 price.

2.2. GRANULARITY, HORIZONS, AND OBJECTIVE FUNCTION

2.2.1. GENERAL STRUCTURE OF THE OPTIMIZATION PROBLEM

Simulations of the gas system in METIS are performed with Artelys Crystal Optimisation Engine and aim at determining a cost-minimizing production plan that ensures a supply /demand equilibrium at each node over the study period, at a daily time step. This is done by solving an optimisation problem whose characteristics are described below.

For each energy, the **supply-demand equilibrium constraint** at each node $\boldsymbol{n}$ and each time step $\boldsymbol{t}$ is the following:

$$Supply_{n,t} = Demand_{n,t}$$

with

[2] Depending on the spatial granularity, a zone may be a subnational region, a country, a set of countries aggregated into one, etc.

$$Supply_{n,t} = \sum_{\substack{producers\ p \\ at\ node\ n}} Production_{p,t} + \sum_{neighbours\ n'\ of\ n} Flow_{n' \rightarrow n,t} + LossOfLoad_t$$

$$Demand_{n,t} = \sum_{\substack{consumers\ c \\ at\ node\ n}} Consumption_{c,t} + \sum_{neighbours\ n'\ of\ n} Flow_{n \rightarrow n',t} + Surplus_t$$

Assets corresponding to consumers at node n are:

- For natural gas: Gas consumption, Gas storage, Gas exports and LNG exports,
- For LNG: LNG terminal,
- For CO2: CO2 emissions.

Assets corresponding to producers at node n are:

- For gas: Gas production, Gas storage, Gas imports, LNG terminal,
- For LNG: LNG imports
- For CO2: Gas consumption

The objective function of the system is the total cost of the system:

$$TotalCost = \sum_{producers\ p} ProductionCosts_p + \sum_{consumers\ p} ConsumptionCosts_p + LossOfLoadCosts + SurplusCosts$$

Where:

- $ProductionCosts_p$ represents the cost of supply from producer p, i.e. production and import costs.
- $ConsumptionCosts_p$ represents the cost or earnings of consuming of consumer p, i.e. CO2 emissions costs and export costs.
- $LossOfLoadCosts$ represent the costs associated to loss of load, computed as the product between the total loss of load (across all zones and all time steps) and the value of lost load (VoLL), usually 3k€/MWh.
- $SurplusCosts$ represents the costs associated to the fact of having surplus energy in some zones, which can be penalised proportionally to the total volume of surplus.

2.2.2. HORIZONS AND OPTIMISATION PROCESS

While for power system models the horizon is broken down into smaller periods to facilitate the optimisation process, gas system models are solved frontally, meaning that all days of the year are solved jointly and simultaneously.

This implies that gas storage injections and withdrawals are planned with perfect anticipation of future needs.

2.3. ASSET MODELS

In METIS, assets of the same type are bundled together into the same asset. For example, by default, all LNG terminals of a zone are aggregated.

Each type of asset has a specific model.

2.3.1. GAS CONSUMPTION

Gas consumption represents daily gas demand. Its parameters are:

- Demand (D_i): daily gas demand in MW.
- CO2 emissions rate (R_i): CO2 emissions due to gas consumption in tonne/MWh.

Gas consumption withdraws gas from the gas node and emits CO2 in the CO2 node of the same geographical zone which is then consumed by the asset *CO2 emissions*.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Consumption variable (≥ 0) $\boldsymbol{CO2_{i,t}}$ [MW]: CO2 emission variable (≥ 0)
Objective
N/A
Constraints
- Demand is set **as an input** $\boldsymbol{P_{i,t}} = D_i$ - CO2 emissions $\boldsymbol{CO2_{i,t}} = D_i \cdot R_i$

2.3.2. GAS PRODUCTION

Gas production represents indigenous production. Its parameters are:

- Pmax ($Pmax_i$): maximal production capacity in MW
- Min load ($Pmin_i$): minimal production capacity in MW
- Availability ($Avail_{i,t}$): availability of the production capacity in %.
- Production cost (C_i): cost associated to production in €/MWh.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Generation variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Production bounded by available capacity: $Pmin_i \cdot Avail_{i,t} \leq \boldsymbol{P_{i,t}} \leq Pmax_i \cdot Avail_{i,t}$

2.3.3. GAS STORAGE

Gas storage represents gas storage facilities. Its parameters are:

- Injection capacity ($Pmaxin_i$): maximal capacity to inject gas from the system into storage facilities in MW.
- Withdrawal capacity ($Pmaxout_i$): maximal capacity to withdraw gas from storage facilities into the system in MW.
- Storage capacity ($Smax_i$): maximal storage capacity in MWh.

- Minimal initial storage level ($minInitStorageLevel_i$): minimal storage level at the beginning of the time horizon in % of the storage capacity. It is important to note that the initial storage level is a variable and is set equal to the final storage level.
- Maximal initial storage level ($maxInitStorageLevel_i$): maximal storage level at the beginning of the time horizon in % of the storage capacity. It is important to note that the initial storage level is a variable and is set equal to the final storage level.
- Minimal storage level ($minStorageLevel_{i,t}$): minimal storage level for each time step of the horizon in % of the storage capacity.
- Maximal storage level ($maxStorageLevel_{i,t}$): maximal storage level for each time step of the horizon in % of the storage capacity.
- Model destocking cost (C_i): cost associated to the withdrawal of gas in €/MWh. This cost is usually set to a very small positive value to avoid numerical artefacts such as simultaneous withdrawal and injection in a storage.

Moreover, although maximal withdrawal and injection capacities are set as an input, real withdrawal and injection depend on the storage level, as specified in the "variable withdrawal/injection capacity" constrains and illustrated on Figure 2.

Mathematical modelling

Indexes
Asset *i* Time step *t* *We note T the last time step.*
Variables
$\boldsymbol{Pout_{i,t}}$ [MW]: Withdrawal variable (≥ 0) $\boldsymbol{Pin_{i,t}}$ [MW]: Injection variable (≥ 0) $\boldsymbol{S_{i,t}}$ [MWh]: Storage variable (≥ 0) (representing storage "at the end" of time step t) $\boldsymbol{S_{i,init}}$ [MWh]: Initial storage variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{Pout_{i,t}}$
Constraints
- Withdrawal bounded by capacity: $\boldsymbol{Pout_{i,t}} \leq Pmaxout_i$ - Injection bounded by capacity: $\boldsymbol{Pin_{i,t}} \leq Pmaxin_i$ - Storage bounded by capacity: $Smax_i \cdot minStorageLevel_{i,t} \leq \boldsymbol{S_{i,t}} \leq Smax_i \cdot maxStorageLevel_{i,t}$ - Initial storage bounded by capacity: $Smax_i \cdot minInitStorageLevel_{i,t} \leq \boldsymbol{S_{i,init}} \leq Smax_i \cdot maxInitStorageLevel_{i,t}$ - Storage dynamics: $\boldsymbol{S_{i,t}} = \boldsymbol{S_{i,t-1}} - \boldsymbol{Pout_{i,t}} + \boldsymbol{Pin_{i,t}}$ *(for t>0)*; $\boldsymbol{S_{i,0}} = \boldsymbol{S_{i,init}} - \boldsymbol{Pout_{i,0}} + \boldsymbol{Pin_{i,0}}$ - Initial storage equal to final storage level: $\boldsymbol{S_{i,init}} = \boldsymbol{S_{i,T}}$ - Variable withdrawal capacity according to storage level: $\frac{\boldsymbol{4} \cdot \boldsymbol{Pout_{i,t}}}{Pmaxout_i} \leq \frac{6 \cdot \boldsymbol{S_{i,t}}}{Smax_i} + \boldsymbol{1}$ - Variable injection capacity according to storage level: $\frac{\boldsymbol{4} \cdot \boldsymbol{Pin_{i,t}}}{Pmaxin_i} \leq -\frac{6 \cdot \boldsymbol{S_{i,t}}}{Smax_i} + \boldsymbol{7}$

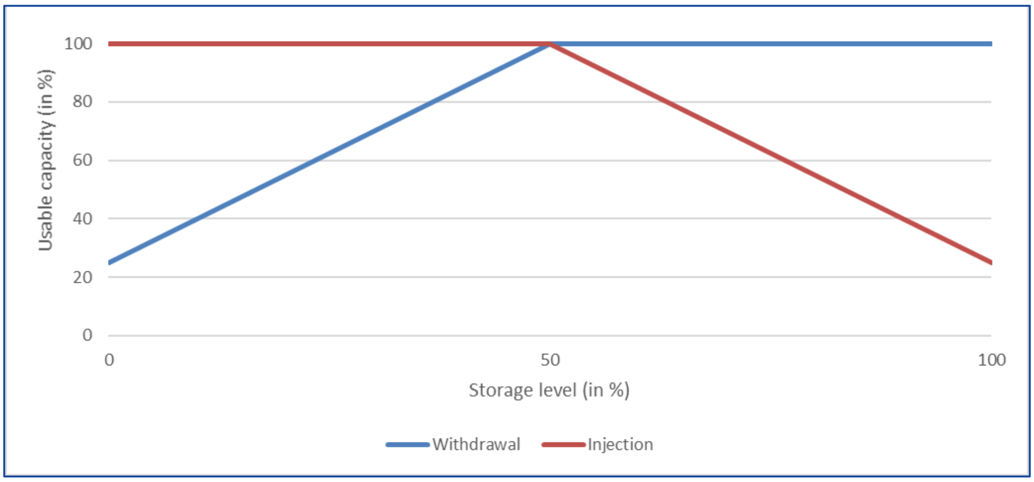

Figure 2: Usable withdrawal and injection capacity depending on the storage level

2.3.4. Gas imports

Gas imports represents import capacities from non-modelled border countries. Its parameters are:

- Pmax ($Pmax_i$): maximal capacity to import gas in MW.
- Availability ($Avail_{i,t}$): availability of the import capacity in %.
- Minimal annual volume ($minTotalVolume_i$): minimal volume of gas which will be imported in the year in MWh.
- Maximal annual volume ($maxTotalVolume_i$): maximal volume of gas which can be imported in the year in MWh.
- Minimal import profile ($minVolumeLevel_{i,t}$): for each time step, minimum share of the maximal annual volume which must have been consumed since the beginning of the year (in %).
- Maximal import profile ($maxVolumeLevel_{i,t}$): for each time step, maximum share of the minimal annual volume which can be consumed since the beginning of the year (in %).
- Cost (C_i): import cost in €/MWh.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Generation variable (≥ 0) $\boldsymbol{S_{i,t}}$ [MWh]: Import volume variable (≥ 0) (representing the remaining available volume for import) $\boldsymbol{S_{i,init}}$ [MWh]: Initial import volume variable (representing the maximal yearly available volume for import)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Import bounded by capacity: $\boldsymbol{P_{i,t}} \leq Pmax_i \cdot Avail_{i,t}$ - Maximal import volume: $\boldsymbol{S_{i,init}} = maxTotalVolume_{\boldsymbol{i}}$ - Steering of the imports throughout the year: $\boldsymbol{S_{i,t}} \leq maxTotalVolume_i - minTotalVolume_i \cdot (1 - \frac{maxVolumeLevel_{i,t}}{100})$ $maxTotalVolume_i \cdot \frac{minVolumeLevel_{i,t}}{100} \leq \boldsymbol{S_{i,t}}$ - Import volume dynamics: $\boldsymbol{S_{i,t}} = \boldsymbol{S_{i,t-1}} - \boldsymbol{P_{i,t}}$ *(for t>0)* $\boldsymbol{S_{i,0}} = \boldsymbol{S_{i,init}} - \boldsymbol{P_{i,0}}$

2.3.5. GAS EXPORTS

Gas exports represents export capacities from non-modeled border countries. Its parameters are:

- Pmax ($Pmax_i$): maximal capacity to export gas in MW.
- Availability ($Avail_{i,t}$): availability of the export capacity in %.
- Minimal annual volume ($minTotalVolume_i$): minimal volume of gas which will be exported in the year in MWh.
- Maximal annual volume ($maxTotalVolume_i$): maximal volume of gas which can be exported in the year in MWh (in %).
- Minimal export profile ($minVolumeLevel_{i,t}$): for each time step, minimum share of the maximal annual volume which must have been consumed since the beginning of the year (in %).
- Maximal export profile ($maxVolumeLevel_{i,t}$): for each time step, maximum share of the minimal annual volume which can be consumed since the beginning of the year.

- Price (C_i): export price (which will provide earnings, in contrary to costs) in €/MWh.

Mathematical modelling

Indexes
Asset i Time step t
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Consumption variable (≥ 0) $\boldsymbol{S_{i,t}}$ [MWh]: Export volume variable (≥ 0) (representing the remaining available volume for import) $\boldsymbol{S_{i,init}}$ [MWh]: Initial export volume variable (representing the maximal initial available volume for import)
Objective
$\boldsymbol{cost_{i,t}} = -C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Import bounded by capacity: $\boldsymbol{P_{i,t}} \leq Pmax_i \cdot Avail_{i,t}$ - Maximal import volume: $\boldsymbol{S_{i,init}} = maxTotalVolume_i$ - Steering of the imports throughout the year: $\boldsymbol{S_{i,t}} \leq maxTotalVolume_i - minTotalVolume_i \cdot (1 - \frac{maxVolumeLevel_{i,t}}{100})$ $maxTotalVolume_i \cdot \frac{minVolumeLevel_{i,t}}{100} \leq \boldsymbol{S_{i,t}}$ - Import volume dynamics: $\boldsymbol{S_{i,t}} = \boldsymbol{S_{i,t-1}} - \boldsymbol{P_{i,t}}$ *(for t>0)* $\boldsymbol{S_{i,0}} = \boldsymbol{S_{i,init}} - \boldsymbol{P_{i,0}}$

2.3.6. PIPELINE

Pipeline represents cross-border gas transmissions. Its parameters are:

- Capacity ($Pmax_i$): maximal transmission capacity in MW.
- Transmission cost (C_i)**:** cost due to exchanges in €/MWh. This cost is usually set to very small positive value to avoid numerical artefacts such as simultaneous import and export between two geographical zones.

Pipelines are unidirectional, i.e. they have to be modelled independently for both directions if a couple of country can exchange gas in both directions.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: flow variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Flows bounded by capacity $\boldsymbol{P_{i,t}} \leq Pmax_i$

2.3.7. LNG TERMINAL

LNG terminal represents LNG gasification terminals. Its parameters are:

- Send-out capacity ($Pmax_i$): maximal capacity to send gas into the system in MW.
- Storage capacity ($Smax_i$): maximal capacity to store LNG in MWh.
- Availability ($Avail_{i,t}$): availability of the import capacity in %.
- Cost (C_i): gasification cost in €/MWh.

LNG terminal storage levels are initially set at half of their storage capacity and are constrained to have the same final value at the end of the year.
The *LNG terminal* asset injects gas into the gas node of a geographical zone and consumes LNG from the LNG node of the same zone, which is supplied by *LNG imports*.

Mathematical modelling

Indexes
Asset *i* Time step *t* *We note T the last time step of the horizon.*
Variables
$\boldsymbol{Pout_{i,t}}$ [MW]: Production variable (≥ 0) (representing gas send-out) $\boldsymbol{Pin_{i,t}}$ [MW]: Consumption variable (≥ 0) (representing LNG consumption) $\boldsymbol{S_{i,t}}$ [MWh]: Storage variable (≥ 0) (representing storage "at the end" of time step t) $\boldsymbol{S_{i,init}}$ [MWh]: Initial storage variable (≥ 0)
Objective
$cost_{i,t} = C_i \cdot Pout_{i,t}$
Constraints
- Gas send-out bounded by available capacity: $\boldsymbol{Pout_{i,t}} \leq Avail_{i,t} \cdot Pmax_i$ - Storage bounded by capacity: $\boldsymbol{S_{i,t}} \leq Smax_i$ - Storage dynamics: $\boldsymbol{S_{i,t}} = \boldsymbol{S_{i,t-1}} - \boldsymbol{Pout_{i,t}} + \boldsymbol{Pin_{i,t}}$ *(for t>0)* $\boldsymbol{S_{i,0}} = \boldsymbol{S_{i,init}} - \boldsymbol{Pout_{i,0}} + \boldsymbol{Pin_{i,0}}$ - Initial storage equal to final storage level: $\boldsymbol{S_{i,init}} = \boldsymbol{S_{i,T}} = 0.5 \cdot Smax_i$

2.3.8. LNG IMPORTS

LNG imports represents the arrival of LNG in LNG terminals. Its parameters are:

- Maximal Imports ($Pmax_i$): maximal import capacity in MW.
- Minimal Imports ($Pmin_i$): minimal import capacity in MW.
- Import Cost (C_i): LNG import price in €/MWh.

It is important to note that imports are set constant throughout the year. The flexibility of LNG imports comes from the storage capacities in LNG terminals. The optimisation thus determines the level on this constant LNG import, transformed into gas and fed into the gas network by LNG terminals.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Generation variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Production bounded by available capacity: $Pmin_i \leq \boldsymbol{P_{i,t}} \leq Pmax_i$ - Constant imports: $\boldsymbol{P_{i,t}} = \boldsymbol{P_{i,t-1}}$ *(for t>0)*

2.3.9. LNG EXPORTS

LNG exports represents the exports of LNG. Its parameters are:

- Exports ($Pmax_i$): exports in MW.
- Export price (C_i): export price (which will provide earnings, in contrary to costs) in €/MWh.

One can note that on contrary to LNG imports, exports are set as an exogenous parameter.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: Consumption variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = -C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
- Exports are set **as an input** $\boldsymbol{P_{i,t}} = Pmax_i$

2.3.10. CO2 EMISSIONS

CO2 emissions represents emissions of CO2 due to gas consumption. Its only parameter is:

- Cost (C_i): cost due to CO2 emissions in €/ton.

Mathematical modelling

Indexes
Asset *i* Time step *t*
Variables
$\boldsymbol{P_{i,t}}$ [MW]: CO2 consumption variable (≥ 0)
Objective
$\boldsymbol{cost_{i,t}} = C_i \cdot \boldsymbol{P_{i,t}}$
Constraints
N/A

3. DATA AND SCENARIOS USED IN METIS GAS SYSTEM MODELS

3.1. SCENARIOS AVAILABLE IN METIS

In the version delivered to the European Commission[3], several scenarios have been implemented:

- ENTSOG **TYNDP2015 GREY scenario** for year 2030
- ENTSOG **TYNDP2015 GREEN scenario** for year 2030
- Artelys S5 scenarios for 2030, based on ENTSOG TYNDP2015 GREY scenario, current infrastructure data and future projects**.** These were used in particular for METIS S5 study on gas PCIs. They include S5-FID scenario, S5-PCI1 scenario and S5-PCI2 scenario.
- European Commission **REF15 scenario** for year 2030
- European Commission **EUCO30 scenario** for year 2030 and 2050

The scenarios delivered to the European Commission share the same modelling options that are described briefly below:

- National granularity:
    - All Member States are represented in the model. In addition to countries from EU28, the following countries may be explicitly modelled: Albania, Bosnia-Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro, Norway, the Republic of Serbia and Switzerland.
    - Other border countries are not explicitly modelled but may be represented by a supplier asset if they export gas to modelled countries. Those include Russia, Belarus, Ukraine, Algeria, Libya and Turkey.
- Simulations over a year, at daily time step performed frontally (i.e. with operational and tactical horizons of 365 days)

These scenarios rely on ENTSOG, GIE and PRIMES inputs and outputs and are complemented with other METIS data such as consumption time series.

3.2. SCENARIO-SPECIFIC DATA

Scenario-specific data are:

- Indigenous production, i.e. annual volumes of gas production per European country
- Annual demand, i.e. annual volumes of gas demand per European country
- Infrastructure assumptions, i.e. whether infrastructure represent current assets[4] or projected ones.
- Fuel costs, i.e. nominal cost for gas and LNG imports.

These main data define and characterize scenarios. Other data are mostly generic and common to all scenarios.

[3] More information at https://ec.europa.eu/energy/en/data-analysis/energy-modelling

[4] Current asset data are published by ENTSOG, GLE and GSE.

Scenario	Years	Indigenous production	Annual demand	Infrastructure assumptions	Fuel costs
TYNDP2015 GREY	2030	ENTSOG TYNDP2015	ENTSOG TYNDP2015 GREY	Projections from ENTSOG TYNDP2015 PCI vision	IEA WEO 2012[5], Current Policies scenario
TYNDP2015 GREEN	2030	ENTSOG TYNDP2015	ENTSOG TYNDP2015 GREEN	Projections from ENTSOG TYNDP2015 PCI vision	IEA WEO 2012, 450 scenario
S5-FID	2030	ENTSOG TYNDP2015	ENTSOG TYNDP2015 GREY	2015 capacities and FID projects from ENTSOG TYNDP2015	IEA WEO 2012, Current Policies scenario
S5-PCI1	2030	ENTSOG TYNDP2015	ENTSOG TYNDP2015 GREY	2015 capacities, FID projects from ENTSOG TYNDP2015 and projects from the first list of PCI[6]	IEA WEO 2012, Current Policies scenario
S5-PCI2	2030	ENTSOG TYNDP2015	ENTSOG TYNDP2015 GREY	2015 capacities, FID projects from ENTSOG TYNDP2015 and projects from the second list of PCI	IEA WEO 2012, Current Policies scenario
REF15	2030	COM REF15	COM REF15	Projections from COM REF15	IEA WEO 2012, 450 scenario
EUCO30	2030, 2050	COM EUCO30	COM EUCO30	Projections from COM EUCO30	IEA WEO 2012, 450 scenario

3.3. DETAILED ASSUMPTIONS

3.3.1. GAS PRODUCTION

To ensure that the annual volume of indigenous production proposed by the scenario is enforced in the METIS computations, *Pmax* and *Min load* of *Gas production* assets are set equal to this volume in MWh divided by 8760, with an *Availability* set to 100%.

Consequently, indigenous production is set constant for all day of the year. Thus the *production cost* has no impact on computations and is set to 0€/MWh.

Parameter	Data
Pmax (in MW)	Equal to annual production (in MWh) divided by 8760
Min load (in MW)	Equal to annual production (in MWh) divided by 8760
Availability (in %)	100%
Production cost (in €/MWh)	0

[5] See [1]

[6] Only includes projects from the first list of PCI which remained in the second list.

3.3.2. GAS STORAGE

The parameters of current infrastructure (2015), in particular injection, withdrawal and storage capacities, have been extracted from GSE published data. For specific projects (FID projects and PCI), capacities have been extracted from ENTSOG TYNDP 2015.

For prospective scenarios, such as TYNDP2015 GREEN, TYNDP2015 GREY, REF15 and EUCO30 scenarios, where usually only withdrawal capacities are provided, injection and storage capacities have been reconstructed by applying the same capacity ratio than current capacities.

In order to simulate the filling of storage to prepare for the winter, the *Minimal storage level* has been set to 100% on the 1st of October. One should note however that since the optimization is performed frontally and that the initial storage level is set freely by the optimization engine, there is a perfect anticipation of storage needs, and the single constraint of having full storages on the 1st of October cannot introduce any security of supply issues.

The model *destocking stock* is set to 0.001 €/MWh to avoid numerical artefacts such as simultaneous withdrawal and injection.

Parameter	Data
Injection capacity (in MW)	Collected from scenario data if available. Else given by keeping the ratio (existing injection capacity / existing withdrawal capacity)
Withdrawal capacity (in MW)	Collected from scenario data
Storage capacity (in MWh)	Collected from scenario data if available. Else given by keeping the ratio (existing storage capacity / existing withdrawal capacity)
Minimal initial storage level (in %)	0%
Maximal initial storage level (in %)	100%
Minimal storage level (in %)	100% on the 1st of October, 0% else.
Maximal storage level (in %)	100%
Model destocking cost (in €/MWh)	0.001

3.3.3. GAS IMPORTS

Pmax correspond to the maximal capacity of pipelines connecting non-European countries to European countries and are given by published capacities from scenario visions or existing infrastructure. *Availability* is set to 100%, except in some test cases of S5 scenarios where it is set to 0 to simulate import disruptions.

The cost of gas imports is collected from IEA World Energy Outlook data. One should note that the gas system module has been designed mainly for supply source dependency and security of supply analyses and thus is not calibrated for gas prices analyses. Prices are set to define a merit order and not to represent accurately gas market prices. To complement the gas system module, the gas market module will include functionalities and models specifically designed for the analysis of gas markets and the impact of infrastructure on gas prices and social welfare.

Parameter	Data
Pmax (in MW)	Collected from scenario data
Availability (in %)	0% in case of import disruption, else 100%.
Minimal annual volume (in MWh)	0
Maximal annual volume (in MWh)	Pmax * 8760
Minimal import profile (in %)	0%
Maximal import profile (in %)	100%
Cost (in €/MWh)	25.7 €/MWh in EUCO30, REF15 and TYNDP2015 GREEN 33.4 €/MWh in S5 scenarios and TYNDP2015 GREY

3.3.4. Gas exports

Gas exports are represented in TYNDP2015 GREEN and TYNDP2015 GREY scenarios. *Pmax* correspond to the maximal capacity of pipelines connecting European countries to non-European countries and are given by published capacities from ENTSOG TYNDP 2015. *Availability* is set to 100%.

Parameter	Data
Pmax (in MW)	Collected from scenario data
Availability (in %)	100%
Minimal annual volume (in MWh)	0
Maximal annual volume (in MWh)	Pmax * 8760
Minimal import profile (in %)	0%
Maximal import profile (in %)	100%
Cost (in €/MWh)	0 €/MWh

3.3.5. LNG Terminal

The parameters of current infrastructure (2015), in particular send-out and storage capacities, have been extracted from GLE published data. For specific projects (FID projects and PCI), capacities have been extracted from ENTSOG TYNDP 2015.

For prospective scenarios (TYNDP2015 GREEN, TYNDP2015 GREY, REF15 and EUCO30), where only send-out capacities were available, storage capacities have been reconstructed by applying the same capacity ratio than current capacities.

Gasification costs are set to 0, i.e. all import costs for LNG are borne by LNG imports.

Parameter	Data
Send-out capacity (in MW)	Collected from scenario data
Storage capacity (in MW)	Collected from scenario data if available. Else given by keeping the ratio (existing storage capacity / existing send-out capacity)
Availability (in %)	100%
Cost (in €/MWh)	0

3.3.6. LNG IMPORTS

LNG maximal and minimal imports are limited by the send-out capacity of the attached LNG terminal.

The cost of LNG imports are collected from IEA World Energy Outlook data.

One should note that the gas system module has been designed mainly for supply source dependency and security of supply analyses and thus is not calibrated for gas prices analyses. Prices are set to define a merit order and not to represent accurately gas market prices. The price of LNG is set higher than the price of gas imports. However, except from REF15 and EUCO30 scenarios, it is cheaper to import LNG than to import gas that has to transit through another EU Member State.

Parameter	Data
Maximal Imports (in MW)	Equal to send-out capacity of attached LNG terminal
Minimal Imports (in MW)	0
Import cost (in €/MWh)	Gas import cost + 0.01€/MWh for REF15 and EUCO30 scenarios Gas import cost + 0.001€/MWh else

3.3.7. LNG EXPORTS

A liquefaction and export terminal is modelled in Norway. Its capacity, which defines its annual volume of export, is set equal to the annual volume of liquefaction/export in REF15 and EUCO30 scenarios divided by 8760. In other scenarios, it is set as the current (2015[7]) annual volume of liquefaction/export divided by 8760.

The *export price* is set to 0€/MWh since it has no impacts on the simulation results, the exports being constant over the year and defined by the capacity.

Parameter	Data
Exports (in MW)	Equal to annual volume of liquefaction/export divided by 8760 for REF15 or EUCO30 scenarios. Equal to annual volume of liquefaction/export in 2015 divided by 8760 for other scenarios.
Export price (in €/MWh)	0

[7] Data collected from COMEXT database

3.3.8. GAS CONSUMPTION

While annual volumes of demand are based on scenario assumptions, time series for demand are generated by Artelys. To assess the benefits of regional cooperation, it is crucial to use consistent weather data through Europe. Indeed, though all countries must prepare to cover their peak demand, it is important to note that all peaks do not occur at the same time throughout Europe.

The following paragraphs describe the methodology which was used to build the demand time series.

The objective is to generate fifty hourly scenarios of demand for each country by means of a statistical model fitted to the following data sources:

- **Historical daily temperature** data from years 1965 to 2014 for all countries from the European Climate Assessment & Dataset project (ECA), see [7].
- **Historical daily demand** from year 2014 from ENTSOG transparency platform, see [2].

In this regard, each demand scenario is modelled as the sum of a thermo-sensitive component and the non-thermo-sensitive one. The thermo-sensitive component is computed by using a piecewise linear model. This model is set up with one threshold and two slopes[8] and calibrated by getting recourse to a *Multivariate Adaptive Regression Splines* method[9] that involves the computation of temperature gradients (MW of demand increase per °C increase) for each country.

As depicted in the figure below for Spain, the temperature scenarios of each country drive its thermo-sensitive demand scenarios by using the country temperature gradients. Then, thermo-sensitive and non-thermo-sensitive demand scenarios are added so as to complete the generation of the country demand scenarios.

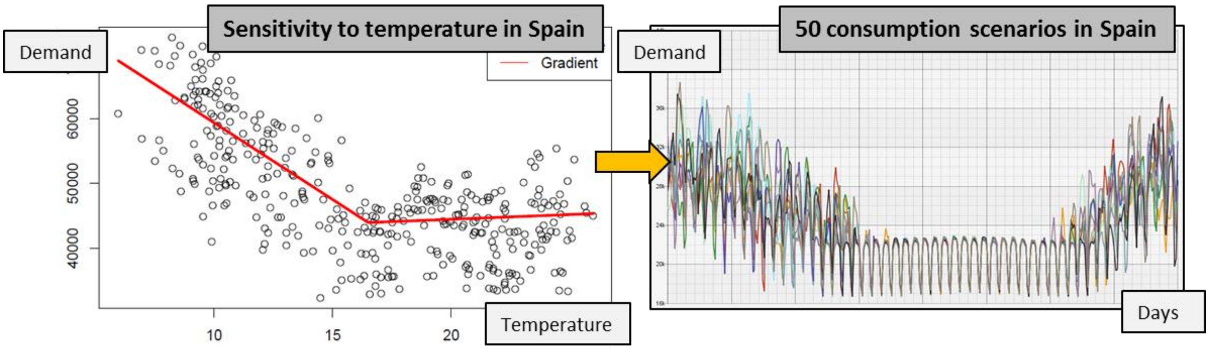

Figure 3: Two gradients accounting for heating effects on Spanish demand

The fifty hourly scenarios of demand are then rescaled linearly so that the average value of demand corresponds to the average value of demand in a given scenario.

Parameter	Data
Demand (in MW)	The average value is scenario-based. Time series were generated by Artelys.
CO2 emissions (in ton/MWh)	0.34

[8] The use of two slopes - one slope associated to low temperatures and one slope associated to high temperatures allows for applying the same approach for each country, with the same number of parameters.

[9] See [23] for the method and [24] for its R implementation.

3.3.9. CO2 Emissions

As the volume of CO2 emissions is set proportionally to the volume of demand (which is exogenous), the price of CO2 emissions has no impact on simulations and is set to 0€/MWh.

3.3.10. Pipelines

The capacity of pipelines are based on scenario data for REF15, EUCO30, TYNDP2015 GREY and TYNDP GREEN. For S5 scenarios, infrastructure from 2015 were collected from ENTSOG map and new projects were collected from ENTSOG TYNDP 2015.

Transmission costs are set to 0.001€/MWh to avoid simultaneous import and export.

Parameter	Data
Capacity (in MW)	Scenario-based or collected from ENTSOG map and ENTSOG TYNDP2015.
Transmission cost (in €/MWh)	0.001

4. Main Outputs And Visualization In The Interface

4.1. Main Key Performance Indicators

In addition to raw inputs and optimization results such as supply time series for each assets or flows of interconnections, the Crystal Super Grid platform provides functionalities to display model parameters and aggregated results of different assets in an ergonomic view using tables, charts or geographical display functions. The main way to display this aggregated data are the Key Performance Indicators whose full list and equations are detailed in the *METIS KPI documentation*.

The following KPIs are among the most useful to analyse the gas system (non-exhaustive list):

- Based on input data:
  - *Demand*, *Installed capacities*, *Storage capacity*
- Based on optimisation results:
  - *Loss of load*, *Expected energy not served* and *Loss of load expectation* to assess uncovered demand in MWh, % and hours.
  - *Supply (detailed)* to see how each zone is supplied in gas (indigenous production, European imports, other gas imports, LNG, storage)

KPIs can be displayed in tables or directly on the map view as shown in the following figure:

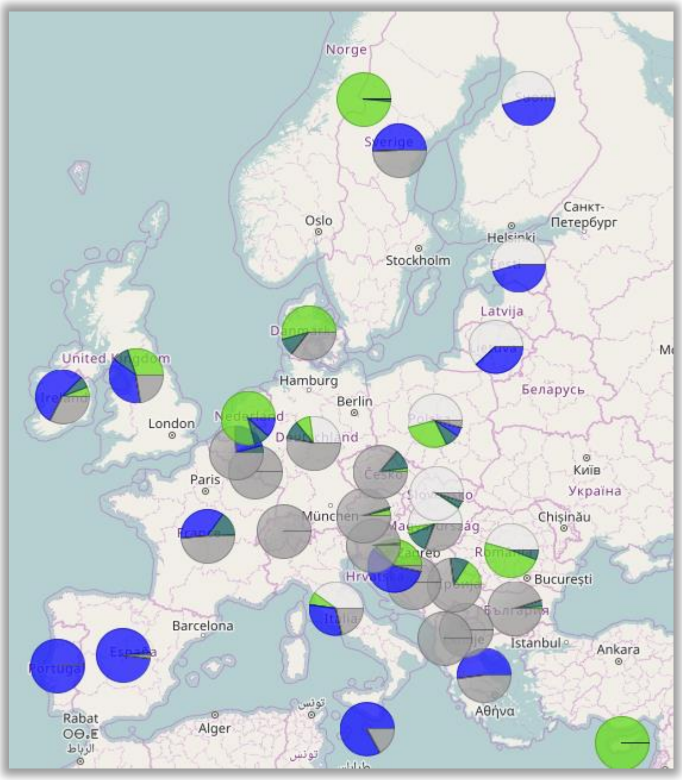

Figure 4: Supply by source and by country, displayed directly on the European map in Artelys Crystal Super Grid

4.2. Main Other Display Features

In addition to aggregated yearly figures (KPIs), it is possible to display time series in a synthetized view to better understand the functioning of the system. In particular, the *Cumulative generation* curve is a very useful feature that illustrates how each zone is supplied in gas with a daily granularity.

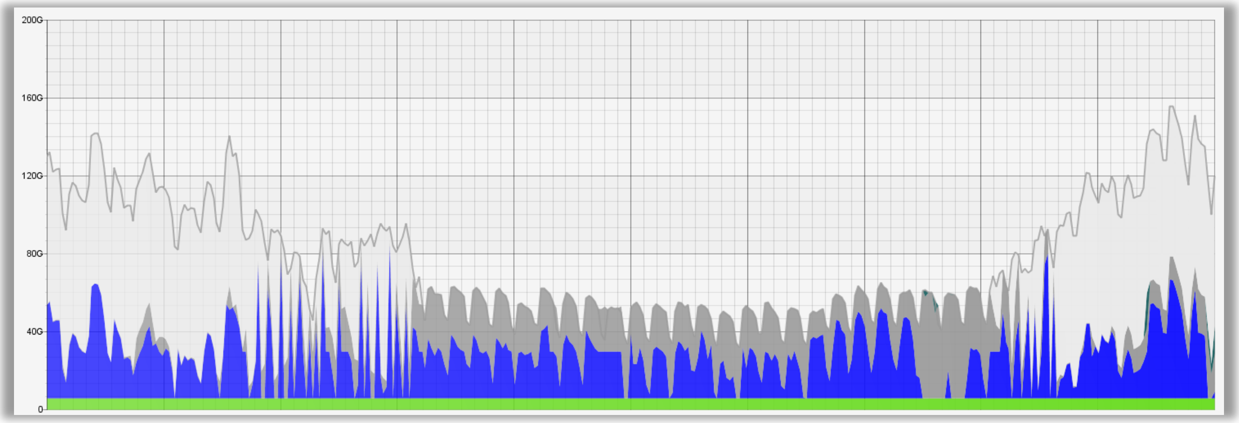

Figure 5: Cumulative generation curve for a year in Italy in 2030, simulated using METIS models and displayed in Artelys Crystal Super Grid

Gas supply – LNG gasification (in blue), indigenous production (in green), gas imports (in white and grey) - are displayed on top of each other, while demand is displayed with a grey curve.

5. REFERENCES

[1] World Energy Outlook 2012, International Energy Agency, 2012

[2] ENTSOG transparency platform: https://transparency.entsog.eu/

[3] ENTSOG transmission capacity map: https://www.entsog.eu/maps/transmission-capacity-map

[4] GLE LNG map: http://www.gie.eu/index.php/maps-data/lng-map

[5] GSE storage map: http://www.gie.eu/index.php/maps-data/gse-storage-map

[6] ENTSOG TYNDP 2015: https://www.entsog.eu/publications/tyndp

[7] European Climate Assessment & Dataset project: http://eca.knmi.nl/

[8] COMEXT database: http://epp.eurostat.ec.europa.eu/newxtweb/

[9] Energy System Wide Cost-Benefit Analysis Methodology, ENTSOG, February 2015: https://www.entsog.eu/public/uploads/files/publications/CBA/2015/INV0175-150213_Adapted_ESW-CBA_Methodology.pdf