Introduction to METIS models

METIS

Prepared by

Paul Barberi (Artelys)
Paul Khallouf (Artelys)
Tobias Bossmann (Artelys)
Laurent Fournié (Artelys)

Contact:
metis.contact@artelys.com
ener-metis@ec.europa.com

Table of Contents

1. INTRODUCTION

METIS is a project[1] initiated by DG ENER for the development of a computer program consisting of modules and datasets titled METIS, 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. METIS first version was delivered at the DG ENER premises in February 2016.

The METIS project provides DG ENER with an in-house tool that can 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 in the impact assessment of the Market Design Initiative.[2]
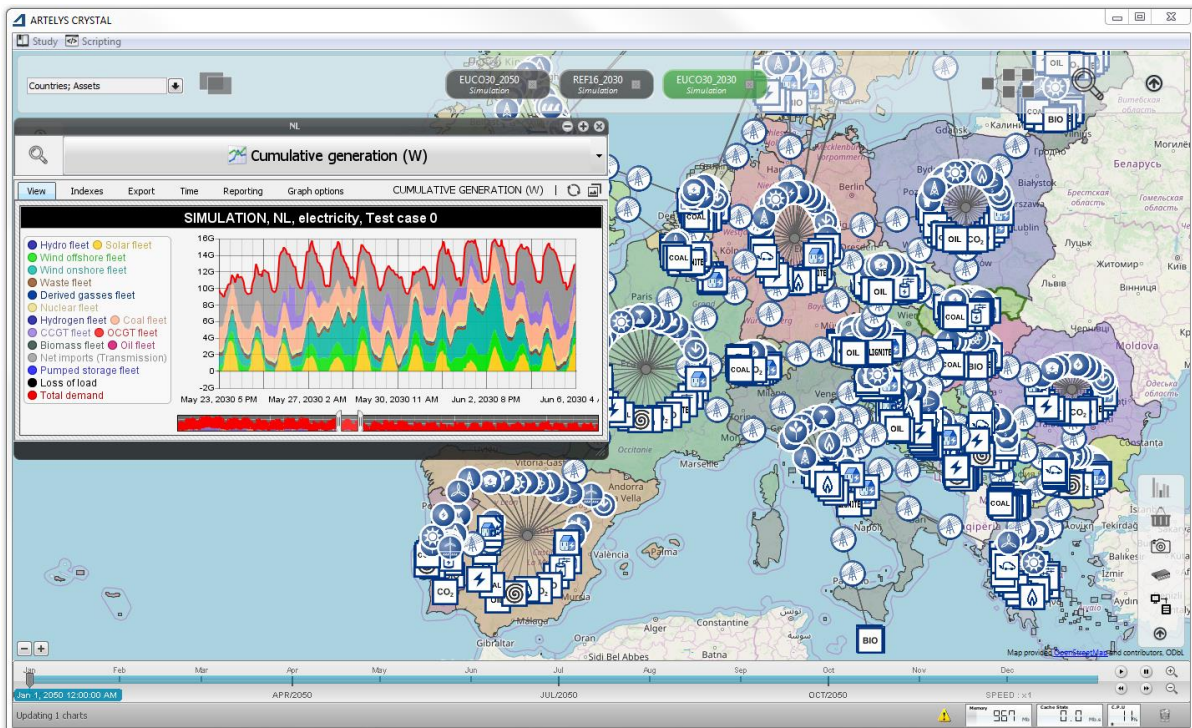
Figure 1: METIS models displayed in the Crystal Super Grid user interface

Purpose of this note

This note should be seen as an entry point for anyone interested in the understanding of the METIS models. One of the main objectives of this note is to present the available documentation, source code and data used in METIS and explain how to use them to understand the model operation. With this note and the associated elements, the reader will be able to fully understand the equations behind the different energy models, apprehend how energy scenarios are built, and learn which indicators are available to analyse the results of a simulated energy scenario.

METIS currently relies on the Artelys Crystal Super Grid Platform (ACSG)[3] to run the model and visualise input data and results. The different METIS models and indicators are run and calculated by the ACSG platform, which also provides a convenient graphical user

---

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

[2] https://ec.europa.eu/energy/sites/ener/files/documents/metis_s12_-_assessing_market_design_options.pdf

[3] https://www.artelys.com/fr/applications/artelys-super-grid

interface allowing users to easily modify, launch the computations of, and analyse METIS energy scenarios.
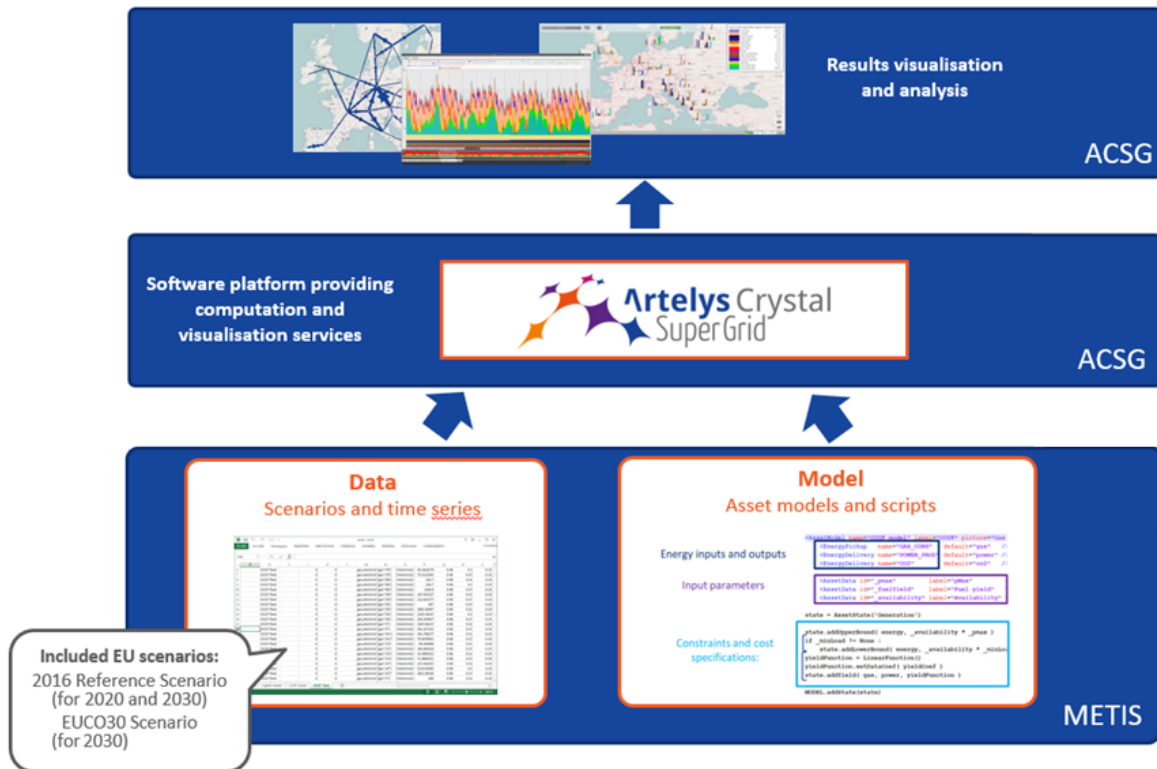
Figure 2 - METIS open-book approach

Scope of the currently available models

This documentation covers the power and gas system METIS modules[4]. They have been designed to address multiple power and gas systems questions, following a welfare-maximisation principle. They can be used to analyse the European power and gas systems' dynamics, by providing production plans, energy flows, production costs, systemic marginal costs, scarcity periods and loss of load, or other standard indicators.

These models can provide answers to various questions such as:

| Generation adequacy analysis,

| Impacts of Renewable Energy Sources integration on the energy system and market functioning,

| Cost-benefit analysis of infrastructure projects, as well as impacts on security of supply,

| Electricity flows between zones

| Gas security of supply analysis

---

[4] The term "module" refers to a set of METIS assets, scripts and data that allow for the modelling of a specific part of the energy system (e.g. power market module, demand module etc.). In contrast, the term "model" refers to the mathematical description of the individual elements of the energy system, i.e. the model of the CCGT asset.

A capacity expansion module is also available, and can be used to joint optimisation of capacity and energy dispatch over the time period of a scenario. It can be applied to the analysis of the economic opportunity of the addition of a new asset or technology (transmission, pipeline, solar fleet, etc…) and optimise its capacity, or optimise the gas peakers capacity to reach a given security of supply criterion, etc.

Additional modules, such as for advanced market analysis (advanced day-ahead/intra-day/balancing markets) or heating sector analysis have been developed and used within the METIS project, but are not covered by this document. Please refer to *METIS Technical Note T8 - Demand and Heat Modules* and *METIS Technical Note T2 - Power Market Module* for additional modelling elements about these modules.

Organisation of this note

| **Section 2** details the licences under which the METIS models and data are published and can be utilised.

| **Section 3** introduces the METIS terminology.

| **Section 4** introduces and presents the main elements available to describe the METIS models and to create energy scenarios.

| **Section 5** is dedicated to the description of the general structure of the model, the optimisation problem it implements, and the way it is solved.

| **Section 6** describes the structure of the METIS database and how to create an energy scenario.

| **Section 7** focuses on indicators available to analyse the energy scenarios.

2. RIGHT OF USE OF METIS MODELS AND DATA

3. METIS TERMINOLOGY

Within the METIS follows a specific structure consisting of different elements. In the following, the major elements are shortly introduced in order to facilitate the reading of this document and published models and data.

Term	Definition
Context	Each energy scenario modelled in METIS is called a context. A context includes all input data (list of modelled countries, asset parameters, timeseries, …) for a given year but also the simulation results (power production of all power plants, reserve procurement, …) once the simulation is done. While the term "energy scenario" refers to a possible evolution of the energy system in the future, the term "context" specifically refers to the implementation of this energy system into METIS, including all models, data, and simulation results. Running sensitivity runs on a given scenario would result in the creation of different METIS contexts, reflecting the same scenario, but with varying parameter values and results.
Delivery Point	Each zone (typically one country) is represented by a delivery point, which connects all assets and their energy flows. One of the main constraints of METIS models is the respect of the supply/demand equilibrium for each energy at each delivery point at any point in time.
Test cases	A given energy scenario can include different timeseries for selected assets, such as the power demand or the renewable production availability. These so-called "test cases" contain each a set of profiles corresponding typically to a given weather year.
Random data	Random data is the name of the data type used to store the hourly timeseries of the different test cases of a parameter. For instance, the power demand of a country can be stored in a random data if the scenario has different test cases.
Asset	Assets are elementary bricks of a METIS context. An asset refers, for example, to a production plant (CCGT, Wind fleet), the power demand of a country or the transmission line between two zones.
Behaviors	Behaviors are specific asset settings that allow to perform different simulations with the same model considering different model characteristics (for example enable reserve procurement, capacity optimisation, etc.)
Scope	A single context can have two scopes, one for dispatch simulation (i.e. optimisation of the utilisation of all assets with the aim to minimize overall system costs) and another one for capacity optimisation (i.e. in addition to the dispatch simulation the capacities of one or several assets are subject to the optimisation).

4. DESCRIPTION OF THE ASSOCIATED DELIVERABLES

This section describes which information is available to understand the METIS models and the available data to build energy scenarios. Three major types of information are available:

- The **html documentation and source code**, where all asset models, scripts to import scenarios and indicators are described.

- During the METIS project, various **technical notes** have been written to describe the different modules developed. While this note provides an overview, the reader can refer to the individual technical notes to obtain more detailed information.

- Different energy scenarios (e.g. the European Commission's Reference scenario and EUCO30 scenario 2030) have been integrated and calibrated in the METIS model, and a **database** has been constituted to gather all the necessary data to create such scenarios. This note describes the structure of this database.

4.1. HTML DOCUMENTATION

Location: HTML documentation

This html documentation aims at providing a global understanding of METIS models. This documentation covers the description of the asset models' equations, the indicators available to analyse the results, import scripts used to create the scenario, and other scripts available for specific uses (e.g. reserve sizing for power scenarios).

The different sections of the html documentation can be accessed through the start home page *index.html*

Figure 3 – html documentation

4.1.1. ASSET MODELS DOCUMENTATION

This section details the different assets that can be used to create a scenario representing a given energy system. The complete description of each asset can be found on the page *Library*. The assets rely on complex models, with advanced features that manage several energies at an hourly granularity. To handle the associated model equations, an API has been developed and its documentation can be found on the page *API documentation*.

4.1.2. INDICATORS

This section focuses on the indicators used in METIS to analyse the results.

4.1.3. CONTEXT ACTIONS

This section details so-called context actions, used to perform specific scripted actions that allow to adapt a given existing context.

4.1.4. IMPORT SCRIPTS FOR CONTEXT CREATION

This section lists the available scripts that can be used to create a new context by importing an existing scenario from the database.

4.2. SOURCE CODE

Location: METIS source code

The source code includes the asset models' definition, and the scripts necessary to create an energy scenario and analyse the different results. It is divided in four parts, as follows:

- *Asset models*: Each asset model is defined in an xml file, which defines its specific modelling and parameters. Please refer to Section 5.3, and to html documentation page *Asset models* for additional information.

- *Indicators*: Several kinds of indicators are available in METIS to analyse the results, from timeseries to analyse the temporal evolution of the production to annual KPI such as the power demand per zone. Please refer to Section 7, and to html documentation page *Indicators* for additional information.

- *Import Scripts*: Different scripts are available to import energy scenario from the database. Please refer to Section 6.2, and to html documentation page *Import scripts for context creation* for additional information.

- *Context actions*: Additional scripts are available to perform different actions on a created energy scenario, such as the reserve sizing for power system. Please refer to Section 6.3, and to html documentation page *Context actions* for additional information.

4.3. TECHNICAL NOTES

Location: Technical notes

In addition to this document on METIS models, several technical notes are available for additional information on the various subjects covered by this documentation:

- *METIS Technical Note T5 - METIS software introduction and architecture:*
  - This note describes the software architecture, and introduces in Section 3 various concepts used in METIS, such as the assets, the delivery points or the test cases.
- *METIS Technical Note T6 - Power System Module:*
  - This note includes additional information about power system models, such asset cluster models to have a better representation of dynamic constraints

of thermal production (starting costs, minimum off-time), hydro-power and storage and reserve supply models.

  | *METIS Technical Note T7 - Gas module*

- This note presents the two representations available for gas infrastructures:
  - The gas system models that are adequate to answer gas security of supply analysis, supply dependence analysis, or study of the impact of infrastructure projects on security of supply.
  - The gas market models where gas prices are endogenous results of the simulation thanks to advanced representation of the gas productions prices and LNG supply routes.

  | *METIS Technical Note T1 - Integration of PRIMES scenarios into METIS*

- This note explains the integration of PRIMES data into METIS, and the methodology used to calibrate the different energy scenarios.

  | *METIS Technical Note T8 - Demand and Heat Modules*

- This note details the demand module that allows to further disaggregate the demand and to perform a detailed modelling of flexible consumers. This includes the disaggregation of the electricity and gas demand between end-uses and the detailed description how the hourly/daily demand profile (and in particular demand peaks) will evolve over time and across different scenarios. The note further introduces the modelling of district heating networks.

4.4. DATABASE

Location: METIS data for European Commission scenarios / METIS data for METIS 2050 scenario[5]

The METIS project included the development of different models to represent the energy systems, but also the calibration of different energy scenarios based on European Commission scenario data. These are prospective scenarios of the European power and gas system for different target years (2020 and 2030).

In addition, a 2050 scenario was created in the context of the preparation of the METIS study "Optimal flexibility portfolios for a high-RES 2050 scenario", reflecting a fully-decarbonised power system.

Each scenario is defined by a set of Excel files (located in the folder *Scenario* of the database), containing all relevant input data of the given power or gas system. These files further refer to a common timeseries database (located in the folder *TemporalData)*, which contains all data featuring hourly or daily granularity.

Information about the sources of the different technical parameters can be found as comments within the scenario Excel files.

The format of this database and the relations with the asset models is explained in Section 6.

Please refer to "*METIS Technical Note T1 - Integration of PRIMES scenarios into METIS*" for more information about the calibration process of these scenarios.

---

[5] Please note that the files containing hourly data for the European Commission scenarios (gathered in the data folders named "EC scenarios_Basics_DB-Temporal…") are stored in separate zipped data packages, that need to be copied into the folder *\METIS data for European Commission scenarios\DB-Temporal*.

5. MODELLING PRINCIPLES AND ASSET MODELS

5.1. MODEL STRUCTURE

In METIS, the energy system is represented by a network in which each node stands for a geographical zone[6] that can be linked to other zones via interconnections (e.g. power transmissions for electricity, or pipelines for gas). At each node are attached assets that represent all consumption, storage and production facilities of energy at this node. The model aims at minimising the overall cost of the system to maintain a supply/demand equilibrium at each node. The temporal granularity of a scenario is user-defined, and is typically hourly for power systems and daily for gas systems.

While the typical METIS models feature a country granularity, zones can also be configured to stand for either NUTS2 zones or for aggregations of country, depending on the needs of the study.

The following sections describe the list of assets included in the model, and specify the main characteristics of the optimisation problem built from the model and of its solving method.

5.2. SIMULATIONS PROCESS

5.2.1. GENERAL STRUCTURE OF THE OPTIMISATION PROBLEM

Simulations of the power system in METIS aim at determining a cost-minimising production plan that ensures a supply /demand equilibrium at each node over the study period, at an hourly time step. This is done by solving an optimisation problem whose characteristics are described below.

The **energy[7] supply-demand equilibrium constraint** at each node n and each time step t is the following:

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

with

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

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

The objective function of the system is the minimisation of total system costs:

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

Where:

---

[6] Depending on the spatial granularity, a zone may be a subnational region, a country, a set of countries aggregated into one, etc. Typically, one node represents a single country.

[7] If the model takes into account reserves, supply/demand equilibrium constraints are set for each reserve type. The objective function remain the same but additional constraints are set on producers, which usually increases the overall costs of the system. More details on reserve constraints are given in *METIS Technical Note T6 - Power System Module*.

- $ProductionCosts_p$ represent the production costs of the producer p, including fuel costs, CO_2 costs, variable operational expenditures (OPEX). Fixed annual capital expenditures (CAPEX) and OPEX can also be considered if relevant.

- $LossOfLoadCosts$ 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 15 k€/MWh.

- $SurplusCosts$ represent the costs associated to the fact of having surplus energy in some zones, which can be penalised proportionally to the total volume of surplus.

5.2.2. *HORIZONS AND OPTIMISATION PROCESS*

METIS models are simulated by performing an optimisation of the production plan over a year, at an hourly time step. This can turn out to be computationally demanding as the typical European model has around 30 assets by country and covers 34 countries, and can be even more complicated with models at NUTS2 geographical granularity.

For that purpose and in order to reflect operational myopia (which reflects better realistic conditions than a perfect foresight approach), the optimisation problem is solved for power systems using a rolling horizon approach. The solution for the whole period is obtained by solving iteratively smaller problems as depicted in Figure 4. Gas system models are solved in a single run, by jointly optimising all days of the year in order to properly capture the annual management of gas storage facilities.

Three horizons are defined:

⎮ The **strategic horizon** corresponds to the full duration of the entire problem,

⎮ The **tactical horizon** corresponds to the length of the smaller optimisation problems horizon,

⎮ The **operation horizon** corresponds to the length of the interval for which the solutions of the small optimisation problem are kept in the full solution.
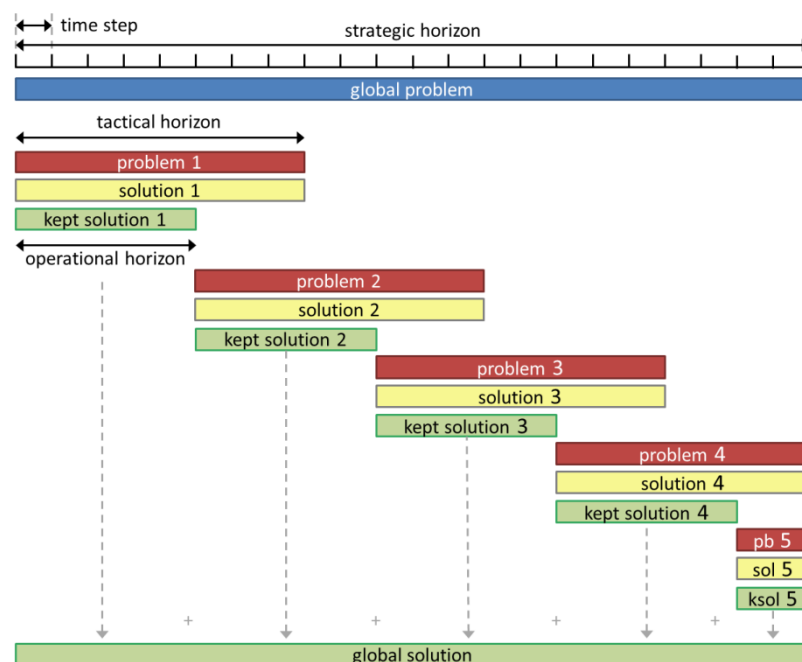

Figure 4: Optimisation process used to simulate METIS models

The resolution consists in solving successive simulation problems over a tactical horizon. The solution kept over each iteration is defined by the operational horizon. At each iteration, the initial states of the assets are set using results obtained from the previous

iteration (states of the assets at the end of previous operational horizon). Figure 4 and Figure 5 describe the simulation procedure and how results are generated.
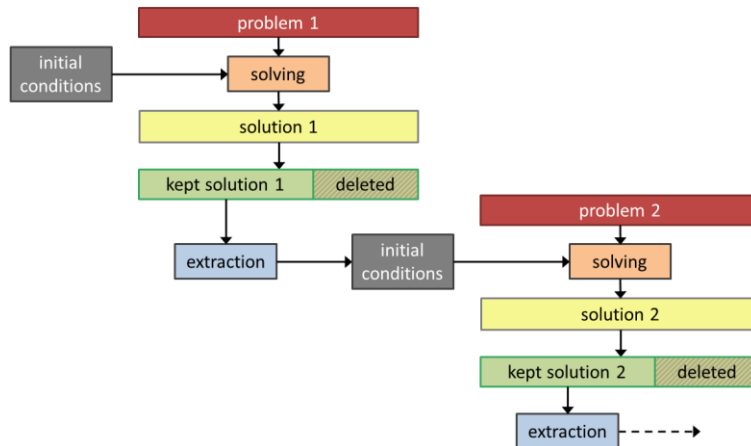
Figure 5: Extraction of final results using the intermediate problems solutions

For the standard METIS European power system model, the strategic horizon corresponds to one year. The tactical horizon is usually set to 15 days and the operational horizon to 7 days. The durations of tactical and operational horizon can also be modified if needed, depending on the user needs. However, since these values have been chosen to balance computational accuracy and computation time, it is advised to keep them unchanged. For instance, increasing the tactical horizon can make the overall solution very anticipative[8].

The METIS gas models require less computation time, because they are at daily granularity while power systems have an hourly granularity. Thus, these gas models are run as a single optimisation problem (all horizons are equal to one year).

5.3. ASSET MODELS

Assets represent the different elements of the power and gas system. There are several categories of assets:
- Physical assets (e.g. production assets such as Nuclear fleet, CCGT…)
- Contract assets (e.g. power demand, gas supply, CO_2 price…)
- Transmissions (e.g. power transmissions, gas pipelines, …)
- Model objects (e.g. minimal reserve requirements)

Assets are the elemental building blocks that can be configured and combined to implement a scenario configuration. Each asset follows a specific modelling approach, relying on specific data.

5.3.1. ASSET TYPES

Different assets represented in the model may stand for different instantiations of similar power system elements, like two cycle gas turbines in two different geographical zones.

In METIS, they would be created using the same mathematical model, with different parameters. The underlying asset model is called a *type*. A library of pre-defined asset types is delivered with METIS.

Each asset type is a coherent model unit and is defined by:

---

[8] A dedicated work has been carried out for long-term hydro storage, since their management required inter-seasonal arbitrages. You can find more information in Section 3.2.2 of the Technical Note T6.

- Input and/or output energy flows
  - One variable by time step and flow
- Costs associated to those flows
- Constraints on theses flows
  - May involve inner modelling module like a storage module
- Other inter-asset constraints may be defined using "model objects" (see below)

Each asset type is defined in an xml. All asset type xml files can be found in the delivered code of METIS, **in the asset models** folder.

The list of all available asset models with their parameters is also available in the html documentation, cf. page **Library Documentation**. The API used to write the model equations defined in the Code section are documented in the **API documentation** page.

Figure 6 - XML code of an asset model (CCGT Fleet)

5.3.2. GROUP OF ASSET TYPES

The different asset types are gathered in different groups to structure the role they have in the energy scenarios:

- **Physical assets** typically refer to production assets or infrastructure assets, such as a power production plant, a power and gas transmission line or a storage facility. Most of these assets can consume and produce energy (such as a CCGT which burns gas to produce electricity) and are multi-energy.

- **Financial assets** represent more simple elements, such as the power/gas demand of a zone, the energy supply contracts (e.g. for coal, oil or biomass) or the CO_2 emissions (i.e. the CO_2 price and the aggregated national emissions).

- **Model objects** do not represent real energy system elements, but are used as a way to set additional constraints to the system with appropriate parameters. They

are for instance used to define how the electricity reserve sizing is performed at a regional level.

The group is defined in the xml file of an asset model, in the field "type"

Figure 7 – Group of an asset model (Nuclear Fleet)

Please note that the database is using a slightly different terminology for the asset groups, with an additional one for interconnections (Asset types *Transmission* and *Pipeline*). Here is the mapping table:

Table 1 - Asset groups mapping between METIS models and the database

Group name in METIS models	Group name in the database
Physical	Asset (for all types excepting *Transmission* and *Pipeline*)
	Transmission (for *Transmission* and *Pipeline* types)
Financial	Contract
Model object	Model Object

5.3.3. BEHAVIOR AND SCOPES

Behaviors

METIS includes modelling options (or "behaviors") that can be activated or disabled depending on the purpose of the study and the level of detail wanted. These behaviors allow to perform more or less detailed simulations with the same model. These behaviors can be available on one or several technologies depending on the model they activate. Behaviors are activated asset by asset and scope by scope. They can be combined, but some specific combinations are considered inconsistent and would not be accepted. When they are activated, some specific parameters are added to the corresponding asset.

For example, behaviors can be used to activate cluster modelling[9] for power systems (behavior *CLUSTER*), or optimise the power/capacity of some asset (behavior *OPTIM_PMAX*).

For each asset type, the behaviors are defined in the respective xml file (cf. Figure 6).

All available behaviors are described in the *Library documentation* section of the html documentation.

Scopes

For each context, it is either possible to run a simple simulation, or to jointly optimise some assets' capacities and the demand/supply flows (i.e. the dispatch). These two simulation modes are available in a single context. These two modes are called "**scopes**", and the only differences between them are the value of the assets' behaviors:

---

[9] METIS can use so-called **cluster models** which allow to take into account dynamic constraints and starting costs in a relaxed (LP) unit commitment, without having to include any binary variables. Please refer to *METIS Technical Note T6 - Power System Module* for more information.

- **SIMULATION**: This is the reference scope for METIS, and can be used for all power and gas models.
- **OPTIMCAPA**: This scope enables capacity optimisation on production or transmission assets. The behavior *OPTIM_PMAX* is only in this scope.

Since the behaviors' values are different between the two scopes, the equations are also different, leading to variations between the simulation results.

6. CREATING A SCENARIO

The import infrastructure of METIS allows to create a power or gas system without having to create the assets one by one. Instead, the list of assets will be written into files that will be handled by METIS via a set of scripts.

The details of scripting will be explained in this section, including a description of the database structure and the available import scripts.

6.1. PRESENTATION OF THE DATA BASE

This section introduces the format of the import files concerning the different assets and their parameters.

6.1.1. GENERAL DATABASE FORMATTING

All assets of each group are summed up in one Excel file.
Thus, there are four Excel files (**assets.xlsx**, **contracts.xlsx, transmissions.xlsx** and **modelObjects.xlsx**), that we call "Import Files", formatted as follow:

- Each tab is dedicated to one asset type
- Each row inside a tab is dedicated to a specific asset

For each asset type, a column represents an attribute required to instantiate the asset type.
The numerical parameters, such as the installed capacity or the availability, can be defined in two manners:

- **As a numerical value.** Then this value will be used for the duration of the simulation
- **As a reference to a time series.** Then the corresponding file will be found from the mapping and read to attach a different value for this parameter for every time step.

The Excel files usually contain all the possible parameters that may be attached to this asset. However, depending on the modelling choices of the study, only some of these parameters will be used.
The last columns of the Excel files aim to define the "behaviors" of each asset and will determine the modelling choices for this asset.
Example of behaviors (more details in the asset documentation):

- CLUSTER: The cluster model is activated (consideration of starting costs, generation level different than running capacity, etc.)
- RESERVE: The reserve requirements and provisions are considered

6.1.2. *PHYSICAL ASSETS: "ASSETS.XLSX"*

6.1.2.1. *MANDATORY COLUMNS*

The following columns are mandatory and must be included in that exact order:

- Id
- Desc
- Zone
- City
- State
- Country
- Owner
- Type
- Category
- Latitude
- Longitude
- FuelType
- Energies
- Inputs
- Outputs

Among the mandatory columns, the following have to be filled, the other ones being only indicative to the user:

- Id: The unique name of the asset
- Zone: The zone that the asset will be included in
- Type: The asset type from the library
- Energies: The list of energy types that are involved in this asset
  - "gas,electricity,co2,syncResUp,syncResDown,mfrrResUp,mfrrResDown"
- Inputs: The energy vectors coming into the asset, defined by a node and an energy with the following convention: {'energyName':'zoneName'}
  - Exemple for a CCGT asset in Bulgaria:
    {'gas':'BG'}
- Outputs: The energy vectors leaving the asset, defined by a node and an energy
  - Example for a CCGT in Finland:
    {'electricity':'FI','co2':'FI','syncResUp':'FI','syncResDown':'FI','mfrrResUp':'FI','mfrrResDown':'FI'}

Important remark: Columns Energies, Inputs and Outputs have to match exactly all energies declared as 'default' in the XML file. For instance, the following energies are declared in the XML of type *OCGT fleet*:

```
<EnergyPickup name="FUEL_CONSUMPTION" default="gas" unit="@ENERHEATVALUE"/>

<EnergyDelivery name="PRODUCTION"         default="electricity" unit="@POWER" />
<EnergyDelivery name="CO2"                default="co2"        unit="@WEIGHT"/>
<EnergyDelivery name="SYNC_RESERVE_UP"    default="syncResUp"   unit="@POWER" behaviors="RESERVE"/>
<EnergyDelivery name="SYNC_RESERVE_DOWN" default="syncResDown" unit="@POWER" behaviors="RESERVE"/>
<EnergyDelivery name="MFRR_UP"            default="mfrrResUp"   unit="@POWER" behaviors="RESERVE"/>
<EnergyDelivery name="MFRR_DOWN"          default="mfrrResDown" unit="@POWER" behaviors="RESERVE"/>
```

Figure 8: Energy mapping as declared in OCGT fleet XML

Consequently, for each zone - say AT as an illustration - the following energy mapping has to be set in the assets import file:

M	N	O
Energies	**Inputs**	**Outputs**
gas,electricity,co2,syncResUp,syncResDown,mfrrResUp,mfrrResDown	{'gas':'AT'}	{'electricity':'AT','co2':'AT','syncResUp':'AT','syncResDown':'AT','mfrrResUp':'AT','mfrrResDown':'AT'}

Figure 9: Energy mapping as declared in the OCGT fleet tab of an import file
(for one particular asset, located in zone AT)

6.1.2.2. OPTIONAL COLUMNS: PARAMETERS AND BEHAVIORS

As many additional columns as desired can be created to set parameter values. Four situations can occur:

- An optional column's header corresponds to a parameter and the column is filled
    - o The column's content will be used as values for the corresponding parameter.
- An optional column's header corresponds to a parameter but is empty
    - o The default value defined in the asset type XML will be used
- A parameter declared in the asset type XML has no corresponding column in the import file
    - o The default value defined in the asset type XML will be used
- An optional column's header does not match any parameter name declared in the asset type XML
    - o The column will be ignored when importing the import file

Finally, for each scope, behaviors can be activated by adding a column with the scope name as header and filling every asset line with the list of all activated behaviors, separated by 'comas' with no space.
For instance, if behaviors *CLUSTER, RESERVE and MUST_RUN* for a given asset and a column SIMULATION is set like this:

AN
SIMULATION
CLUSTER,RESERVE

Behaviors *CLUSTER* and *RESERVE* will be activated. Behavior *MUST*_RUN will be deactivated.
If a scope is not set in the import file (that is, if no column has its name as header), all behaviors are deactivated.

6.1.3. FINANCIALS ASSETS: "CONTRACTS.XLSX"

As explained in the first section, each tab of the Excel file is dedicated to a type of contracts
The following columns are mandatory and must be included in that exact order:

- Id
- Desc
- Zone
- Country
- Owner
- Type
- Category
- Latitude
- Longitude
- Energy
- Energy zone

Among mandatory columns, the following have to be filled, the other ones being only indicative to the user:

- Id: The unique name of the asset
- Zone: The zone that the asset will be included in
- Type: The asset type from the library
- Energy: The type of energy that will be involved in this asset
  - Example: biomass
- Energy Zone: The energy vector related to the asset, defined by a node and an energy
  - Example: {'co2':'DK'}

Unlike physical assets, contracts may be created with a different energy than the one declared as 'default' in the XML. As an example, the different assets have the same underlying type *Reserve well* with different energies:

Id	Desc	Zone	Country	Owner	Type	Category	Latitude	Longitude	Energy	Energy zone
Well_syncResUp_AT		AT	AT		Reserve well		0	0	syncResUp	{'syncResUp':'AT'}
Well_syncResDown_AT		AT	AT		Reserve well		0	0	syncResDow	{'syncResDown':'AT'}
Well_mfrrResUp_AT		AT	AT		Reserve well		0	0	mfrrResUp	{'mfrrResUp':'AT'}
Well_mfrrResDown_AT		AT	AT		Reserve well		0	0	mfrrResDow	{'mfrrResDown':'AT'}

Figure 10: Different contract of same type using different energies

Setting parameter values works exactly like for physical assets. Optional columns can be added with:

- *The considered parameter's name as header*
- *A value for each particular asset (each corresponding to a line in the same asset type tab)*

If a parameter is not set for a given asset or if the entire column is missing, default value declared in the asset type XML file will be used. If a parameter is mentioned in the import file but is not declared in the corresponding XML file, the value filled in the import file will be ignored.

6.1.4. *TRANSMISSIONS: "TRANSMISSIONS.XLSX"*

The following columns are mandatory and must be included in that exact order:

- Id
- Desc
- InputZone
- OutputZone
- Owner
- Type
- Energy
- InputEnergyZone
- OutputEnergyZone
- pmax

Among mandatory columns, the following have to be filled, the other ones being only indicative to the user:

- Id: The unique name of the asset
- InputZone: The zone that the transmission will start from
- OutputZone: The zone that the transmission will arrive to
- Type: The asset type from the library
- Energy: The types of energy that can use the transmission line
- InputEnergyZone: The energy zone that the transmission will start from, defined by a node and an energy

- OutputEnergyZone: The energy zone that the transmission will arrive to, defined by a node and an energy

Setting parameter values works exactly like for physical assets. Optional columns can be added with:

- *The considered parameter's name as header*
- *A value for each particular asset (each one of them corresponding to a line in the same asset type tab)*

If a parameter is not set for a given asset or if the entire column is missing, default value declared in the asset type XML file will be used. If a parameter is mentioned in the import file but is not declared in the corresponding XML file, the value filled in the import file will be ignored.

6.1.5. MODEL OBJECTS: "MODELOBJECTS.XLSX"

The following columns are mandatory and must be included in that exact order:

- Id
- Desc
- Category
- Type
- Latitude
- Longitude

The other columns should match the model object parameters defined in the associated xml file.

6.1.6. THE TEMPORAL DATABASE

Times series are separated from import files so that they can be shared between different scenarios, rather than being attached to only one of them.
The previous sections explained how to set numerical parameters directly in the import files as a numerical value that will be constant throughout the context. However, a parameter value can also be linked to a csv file containing time series. This last possibility will be explored in this section. The section is dedicated to the understanding of how to set time series as parameters in METIS

6.1.6.1. TIME SERIES SETS

All timeseries are stored in csv files. Different sets of time series may be defined and used simultaneously. This section only explains the construction of one set, assuming all needed data for a given scenario is included in this same set[10].

A time series set is constituted by a repertory containing:

- One file named ***DB-Temporal.csv***
    - o Referred to as 'mapping file'
- One folder named **DB-Temporal**

The folder DB-Temporal basically contains all time series csv files.
The mapping file *DB-Temporal.csv* allows one to match time-dependent data keys and csv files, corresponding to different version of the data.

---

[10] It is possible to uses more than one timeseries data sets in the context creation process. Please refer to the *mergeInfos(..)* method of the import scripts API for more information on how to merge different temporal data sets. Current import scripts are using this functionality (execution_gas.py, and execution_power_system_with_demand_decomposition_by_end-use.py)

6.1.6.2. *CSV FILE FORMAT*

Time series have to be written in the following csv format, one csv file being used for one piece of data like the national demand in France:

	A	B	C	D	E
1	TimeZone	Etc/GMT-1	Etc/GMT-1	Etc/GMT-1	Etc/GMT-1
2	DateTime	Test case 00	Test case 01	Test case 02	Test case 03
3	01/01/2014 00:00	68515,0295	65155,3448	55811,5125	57784,5129
4	01/01/2014 01:00	67675,386	64315,7012	54971,8689	56944,8694
5	01/01/2014 02:00	65641,0745	62281,3898	52937,5575	54910,558
6	01/01/2014 03:00	62142,0154	58782,3306	49438,4983	51411,4988
7	01/01/2014 04:00	59897,5208	56537,8361	47194,0038	49167,0042

Figure 11: time series csv file format

The first column gives the date time series to match each value with a time step. If imported in a context configured on a different year, the imported date time series will be shifted to the context year in the import script.
Every other column corresponds to a realisation of weather conditions, referred to as test cases.
The two first lines gives respectively the time zone to be used and test cases names. Test case names have to be

- 'Test case 0' -> 'Test case 9' if there is at most 10 test cases
- 'Test case 00' -> 'Test case 99' if there is more than 10 test cases

To avoid inconsistency in data, it is strongly recommended to declare the same time zone in all csv files and to set the context time zone to the same one. 'Etc/GMT-1' was used everywhere in the METIS database and in delivered contexts.

Power and gas demand timeseries are based on 52 weather years. Test case 00 replicates year 1964's weather conditions and Test case 51 replicates year 2015's weather conditions. The chronological order is respected between test cases 00 and 50.

National RES availability profiles are based on historical weather data from 2001 to 2010 processed to match PRIMES average capacity factors. In order to capture RES production and demand correlations, the 10 different profiles corresponding to years 2001 to 2010 match Test case cases 37 to 46 in that order (see previous point on demand test cases). Test cases 00 to 36 and 47 to 51 are cyclic repetitions of these ten historical profiles.

6.1.6.3. *THE IMPORT FILE SYNTAX OF TIMESERIES*

The cell format is **RANDOM({zone:AT,tech:Hydro RoR fleet,data:_availability})**

The structure is the following:

- RANDOM indicates that this is a reference to a time series
- It should be followed by parentheses containing the following between brackets and separated by commas (it is a python-dict-like structure with keys and values):
    - zone: a given zone indication (usually the considered asset's zone)
    - tech: a given technology indication (usually the considered asset's type)
    - data: a given data indication (usually the considered parameter's name)

The keys zone, tech and data, together with a version tag enable to point to a specific time series, using the mapping file, as explained in the next section.

6.1.6.4. THE MAPPING FILE

The mapping file purpose is to match keys values to csv files. The mandatory columns are:

- Class
  - o Can only take 'RandomValueData' as value
- Data Name
  - o Data identification key
- Technology
  - o Data identification key
- Zone
  - o Data identification key
- GMT
  - o Time zone indication
- Location
  - o csv file name
- Source
  - o Version tags

Except GMT, all mandatory columns must be filled as explained in this section.
Each piece of data is identified by three keys in the mapping, to be respectively matched with the three keys defined in the import file syntax:

Key name in mapping file	Key name in import file
Data Name	data
Technology	tech
Zone	zone

Note: there is no constraints on the values used. The only important thing for the matching to occur is that the same values are attributed to Data Name and data, to Technology and tech, to Zone and zone.

For instance *RANDOM({zone:AT,tech:Hydro RoR fleet,data:_availability})* in an import file parameter column will be matched with the following line in the mapping file:

A	B	C	D	E	F
Class	Data Name	Technology	Zone	GM	Location
RandomValueData	_availability	Hydro RoR fleet	AT		availability_AT_HydroRoR.csv

The name of the csv file that will be used eventually is given in the column "Location". No complete path is required since all csv files need to be in the DB-Temporal folder located right next to the considered mapping file.

An important point is that several versions of a given piece of data may be available in the DB-Temporal folder for the user to use them in different scenarios. To deal with that case, the column Source must be filled with a list of tags. When importing a context in METIS, one and only one tag has to be chosen (see import script section).

In the following example, different csv files are associated to the triplet ('_demand', 'Power demand', 'AT') corresponding to different scenarios' assumptions. However, one source tag may only be attributed once to a triplet allowing one to distinguish them in the import script.

Class		Data Name		Technology		Zone		GN		Location		Source
RandomValueData		_demand		Power demand		AT				demand_AT_PRIMES_EuCo27_2030.csv		PRIMES_EuCo27_2030
RandomValueData		_demand		Power demand		AT				demand_AT_PRIMES_EuCo30_2030.csv		PRIMES_EuCo30_2030
RandomValueData		_demand		Power demand		AT				demand_AT_PRIMES_EuCo30_2050.csv		PRIMES_EuCo30_2050
RandomValueData		_demand		Power demand		AT				demand_AT_PRIMES_REF16_2030.csv		PRIMES_REF16_2030
RandomValueData		_demand		Power demand		AT				demand_AT_PRIMES_REF16_2020.csv		PRIMES_REF16_2020

6.1.7. _INTERMEDIATE DELIVERY POINTS_

Several delivery points can be created for a given energy in a given zone. This feature can be used to:

- Separate two circuits for the same energy in the same zone
- Represent a variant of some energy carrier ('light oil' as another 'oil' delivery point for instance)

METIS gas models make use of the first application to separate LNG and gas for each zone.

- A delivery point Z_lng (distinct from the main delivery point of the zone) is created for each zone Z having the LNG terminal assets.
- LNG imports in zone Z arrive on delivery point Z_lng
- Each LNG terminal asset in zone Z consumes on delivery point Z_lng and produce on delivery the main delivery point of the zone
- The Gas consumption/Gas storage/Pipeline assets consume on the main delivery point of the zone

Figure 12: Intermediate delivery point used to separate LNG imports in Spain

The following syntax should be used:

N	O
Inputs	**Outputs**
{'gas':'I_lng_BE'}	{'gas':'BE'}

{'E':'I_X_Z'} maps the flow of energy E with an intermediate delivery point associated to zone Z and name X_Z.

6.2. IMPORT SCRIPTS

To create a new context, import scripts have been developed to read the scenario data from the database, and build a scenario in the METIS software. Import scripts allow to create complex contexts from Excel files, but also to perform post treatment of the newly created scenario, like parameter value modification, zone aggregation, adding assets from another scenario…

6.2.1. ORGANISATION OF THE SCRIPTS

The import scripts folder includes all scripts related to the import process in METIS. The scripts can be divided in two parts.

6.2.1.1. TOP-LEVEL IMPORT SCRIPTS

Location: at the root of the user folder

A top-level import script is used to define all relevant parameters related to a scenario that shall be imported. At the end of the script, a second-level import script is executed to perform the import steps according to the above defined parameters.

6.2.1.2. SECOND-LEVEL IMPORT SCRIPTS

Location: in the *scripts* folder

A second-level import script uses the parameters defined in the top-level import script to import the relevant data, and at the end it uses these data to create a context in the current study of METIS.
After the data import but before the context creation, it is also possible to perform some extra steps to change some parameters of the context. For instance, it is possible to add extra assets from another scenario, change some asset parameter values, and also perform zone aggregation.
All these steps rely on common utility functions that are documented in *the import scripts API* section of the html documentation.
These scripts are executed from a top-level import script, and *should not* be executed directly.

6.2.2. DETAILED IMPORT SCRIPT PROCESS

6.2.2.1. IMPORT SCENARIO TEMPLATE

This script allows to import scenario with a standard format:
 | one to four import Excel files:

- assets.xlsx
- contracts.xlsx
- transmissions.xlsx
- modelObjects.xlsx

They are not compulsory, and the user has the possibility to import a subset of these files.

| A single temporal DataBase (with a single source tag)

As described before, this script is divided in two files:

| *import_scenario_template.py* for the import parameters definition
| *execution_scenario_template.py* to fetch data from the DataBase and create the context

It is important to note that all import scripts share the same structure. The following import scripts are derived from import scenario template, and only implement additional features (such as the creation of assets' groups to have an easier way to set behaviors, or the possibility to import assets from more than one Excel files).

6.2.2.2. *IMPORT GAS SCENARIOS*

A specific top-level import script has been created to import gas scenarios. It has exactly the same structure as the *import_scenario_template.py* script, but with some predefined parameter values that are used for the gas model.
For instance, the granularity of simulation is daily, with a single optimisation problem of one year, and the temporal DataBase path is set to the specific folder used for gas temporal data.

6.2.2.3. *IMPORT POWER SYSTEM SCENARIOS*

A specific top-level import script has been created to import power system scenarios. It has a similar structure as the *import_scenario_template.py*, but with additional import parameters used to change some asset parameters before the context creation.

6.2.2.4. *IMPORT POWER SCENARIOS WITH DEMAND DECOMPOSITION BY END-USE*

In addition to the *import_power_system.py* script, there is a dedicated top-level import script to handle power scenarios with demand decomposed by end-use. This script, *import_power_system_with_demand_decomposition_by_end-use.py*, loads additional data specific to the demand decomposition, such as the different end-uses' timeseries.
With the parameter *useFlexibleDemandAsset* set to True, *Demand-response*, *Electric vehicles* and *Heat Pump* assets are flexible, and can adapt their power consumption profile according to the electricity prices (behavior "Non-flexible demand" is not activated).

6.3. **CONTEXT ACTIONS**

After the context creation, several scripts are available to modify the scenario. It is for example possible to modify some assets' parameters data from a csv file (e.g. change the capacity of several power transmissions), or estimate for each country the operating reserve sizing, according to penetration of non-dispatchable energy sources (wind, solar) and power demand forecast errors.

These context actions are located in the *Context actions* folder on the METIS source code, and are documented in the *Context actions* section of the html documentation.

7. ANALYSING INPUT DATA AND RESULTS

Several kinds of indicators are available in METIS to analyse and illustrate the input data and results (e.g. timeseries to follow the temporal evolution of the production, or annual KPIs such as the power demand per zone):

| **KPI**: These key performance indicators calculate aggregated values of the context data. METIS includes a large set of indicators, covering supply/demand equilibrium (e.g. power/gas demand per zone, the power production detailed by production type, the unserved energy per zone), energy flows between zones (e.g. import capacities, transmission usage) or economic revenues (e.g. producer surplus, Welfare, Investment costs).

| **Decorators**: In order to have a better representation of the data (inputs and results), the previous listed KPI can be represented on a map. Some specific indicators have also been developed to represent the context parameters and results on a map (e.g. the countries' borders, a dynamic view of the energy flows between the different zones, etc.).

| **Zones and delivery points:** In addition to aggregated data, timeseries indicators are available per zone to have a better representation of the temporal evolution of the energy flows. It includes for example the cumulative generation of electricity production types or the net demand timeseries.

| **Assets:** For a given asset, structured timeseries' results are built upon raw simulation results. They bring an easier representation of the asset behavior. For example, the asset production view represents the temporal evolution of the power production, but also the reserve procurement and the minimal generation bound.

The code of the different indicators is located in the *Indicators* folder, in the METIS source code. The detailed documentation of the different indicators can be found in the *Indicators* section of the html documentation.