



METIS Technical Note T5

METIS software introduction and architecture



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Table of Contents

1.	Introduction.....	5
2.	Software architecture.....	6
2.1.	Software architecture.....	6
2.1.1.	METIS configuration files.....	6
2.1.2.	METIS database.....	7
2.1.3.	Artelys Crystal Super Grid Platform.....	7
2.2.	Metis modules.....	7
2.2.1.	Power system.....	7
2.2.2.	Gas system.....	8
2.2.3.	Power market.....	8
2.2.4.	Stochasticity.....	8
2.2.5.	Bidding.....	8
2.2.6.	Reporting.....	8
3.	Concepts used in Artelys Crystal Supergrid Platform.....	10
3.1.	Energies and other traded commodities.....	10
3.2.	Assets, asset types and asset models.....	10
3.3.	Energy Zones and Delivery Points.....	10
3.4.	Multi-energy system.....	11
3.5.	Horizons.....	11
3.6.	Contexts and Studies.....	11
3.7.	Test cases and random data.....	11
3.8.	Scenarios.....	12
4.	User types.....	13
4.1.1.	Decision makers.....	13
4.1.2.	Analysts.....	13
4.1.3.	Developers.....	14
5.	Documentation list.....	15

1. INTRODUCTION

METIS is an on-going project¹ initiated by DG ENER for the development of an energy modelling software covering the whole European system for electricity, gas and heat. 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. METIS was used, along with PRIMES, in the impact assessment of the Market Design Initiative.

This technical note is an introduction to METIS software describing the software **architecture**, main **concepts** and **user types**.

The present document is organised as follows:

- | **Section 2** is dedicated to software architecture with the definition of modules and a presentation of the software parts and technologies (METIS database, METIS configuration, Artelys Crystal Supergrid Platform).
- | **Section 3** defines the main concepts used in the software such as studies, contexts, test cases, etc.
- | **Section 4** describes the different user types (analyst or developer) with the list of features that apply to each of them.
- | **Section 5** lists documentation on Metis and the scope of each document : technical notes on each module describe the models and data used, and practical information on software usage can be found in the quick user guide or in training manuals.

For transparency reasons, all deliverables related to METIS, including all technical specifications documents and studies, are published on the website of DG ENER².

¹ (METIS) http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf

² <https://ec.europa.eu/energy/en/data-analysis/energy-modelling/metis>

2. SOFTWARE ARCHITECTURE

METIS has a modular structure that makes it easy to extend the software through the addition of new modules or the adjustment of existing ones.

2.1. SOFTWARE ARCHITECTURE

METIS relies on Artelys Crystal Super Grid Platform. This platform, provides a user interface and scripting capabilities to extend the software without writing compiled code. The Artelys Crystal Super Grid Platform scripting capabilities relies on a public API of the platform and uses Python language for the scripts. The Python language interpreter embedded into Artelys Crystal is Jython³ which supports Python 2.7 and enables Crystal to provide direct access to many Java objects from a scripting environment. This has some limitations however, especially, native CPython extensions (such as Numpy) cannot be used within Jython.

METIS modules are implemented using the scripting capabilities of the Artelys Crystal Super Grid Platform.

The Artelys Crystal Super Grid Platform relies on the Artelys Crystal Optimization Engine which provides a high-level modeling language for power systems modeling.

The Artelys Crystal Optimization Engine, translates the high-level model into linear programs using optimized formulations, implemented by numerical experts. These linear programs are then optimized using FICO Xpress optimization solver.

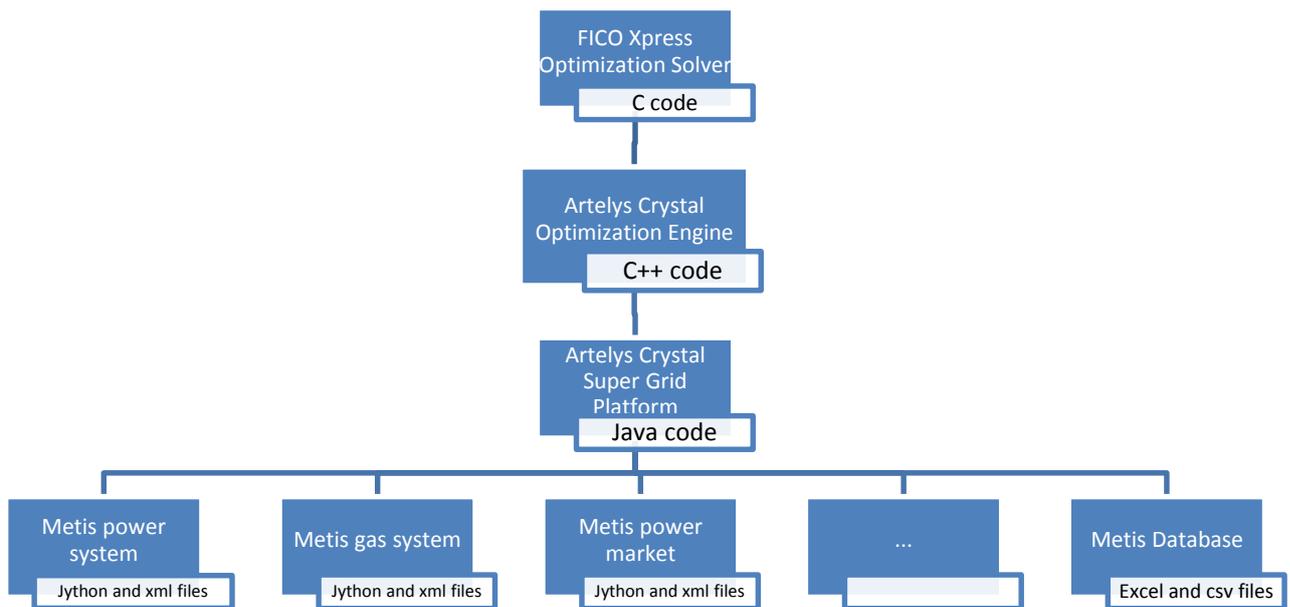


Figure 1. METIS Architecture

2.1.1. METIS CONFIGURATION FILES

METIS modules each correspond to a set of features related to a type of problem. Adding these features is done by modifying the METIS configuration files. Such files contain the code for:

- | The library of asset types and their models (parameters and equations),
- | The list of custom result views and their implementation,

³ Jython is a Java interpreter for Python, supported by the Python Software Foundation and available under the open-source Jython license, see <http://www.jython.org/> for more details.

- | The list of KPIs (Key Performance Indicators) and their implementation,
- | The list of map decorators and their implementation,
- | The list of import scripts to create studies with data from the database.

2.1.2. METIS DATABASE

The METIS database is a set of Excel and csv files containing data compiled from other sources (PRIMES, ENTSOE, ENTSOE, EMOS) organised in a structured format so that the Crystal Super Grid Platform can import them easily.

Each long term scenario (e.g. PRIMES REF16 2030, PRIMES EuCo30 2030) is represented by a file directory containing all asset parameters describing the European system.

The METIS database also includes a Temporal Database directory to enable the Stochasticity Module. This directory contains 50 temporal test cases of demand and RES availability. For market simulations, demand forecasts have also been generated and included in the database (see Stochasticity Module).

2.1.3. ARTELYS CRYSTAL SUPER GRID PLATFORM

The METIS configuration and modules are powered by Artelys Crystal Super Grid Platform (property of Artelys). The platform provides a common framework for energy modelling and a unique user interface to plug in all functionalities.

It provides all the main advanced user views such as the map view or the time series view and services such as imports and exports, persistence, interacting with the simulation engine, etc.

It also provides an extensive set of functions (java developer API) that can be called in METIS configuration scripts in Jython to configure studies with data from the database, define results display and create custom indicators.

The model runs are performed by Crystal Optimization Engine, a software dedicated to large energy system optimization (property of Artelys). The optimization problem is solved with FICO Xpress, a commercial optimization solver developed by FICO and distributed with Crystal applications.

2.2. METIS MODULES

2.2.1. POWER SYSTEM

The power system module allows to model power systems. The version delivered to the European Commission includes models of the European power system, representing power production, consumption and transmission assets. It takes as input data for production capacities, annual demand, annual renewable power generation, NTCs as well as fuel and CO₂ prices for all 28 EU member states (plus complementary data for the 6 non-EU countries Switzerland, Norway, Serbia, Macedonia, Montenegro and Bosnia-Herzegovina from external sources).

The system operations are simulated on a full year with hourly time steps to minimize operation costs. Results can be analysed using the available Key Performance Indicators (KPIs – around 50 are currently available). Detailed hourly results are also available for each element of the model (generation, fuel consumption, CO₂ emissions).

The power system module embeds a model for reserve (FCR, aFRR, mFRR) whose allocation can be optimised simultaneously with the power dispatch, and which can be activated or deactivated at the will.

The power system module can be used to conduct system studies such as generation adequacy analysis, impact of RES integration on operations, cost-benefit analysis of infrastructure projects, etc.

It can also be used to analyse several aspects of market design such as reserve dimensioning and allocation, market coupling, etc.

2.2.2. GAS SYSTEM

The gas system module is the equivalent of the power system module for gas systems. It embeds gas-specific assets and performs simulations a daily time step. This module can be used notably for security of supply or supply source dependence studies.

2.2.3. POWER MARKET

This module complements the power system module with models for intraday and balancing markets. These models take into account forecast and imbalance data to build-up on the results of the power system module. The intraday model indeed allows to assess the impact of the re-adaptation of the generation dispatch up-to real-time, while the balancing model allows to simulate the real-time dispatch of reserve units to face imbalance.

This module has been used in the impact assessment of the Market Design Initiative in conjunction with the Power System Module.

2.2.4. STOCHASTICITY

The Stochasticity Module allows to generate data for both system and market modules. Data generated by the stochasticity module are fed into the METIS database and include time series for:

- | RES generation and demand by country, for up-to 50 weather scenarios,
- | RES generation and demand forecasts by country,
- | Imbalances,
- | Reserve sizing.

The reserve sizing module takes into account the sizing options determined by the user such as hourly or annual sizing, regional cooperation, symmetry.

2.2.5. BIDDING

Four bidding strategies are integrated as a post treatment of power system simulations (without reserve) that modify bid prices for producers and affect their revenues:

- | Marginal: bidding at actual variable electricity generation costs; serves as the reference,
- | Strategic: bids include a mark-up to take advantage of the cost gap with the next more expensive bid,
- | Oligopoly: the user can specify power plant ownership distribution, so that each producer bid include a mark-up to take advantage of the cost gap with the next producer of a different owner.
- | Fixed-operating costs: bids include fixed costs (CAPEX and/or OPEX)

2.2.6. REPORTING

The reporting module is entirely customizable by the analyst. It is based on a window that allows the user to see different KPIs at the same time and configure the tables and graphs. The user can choose to filter or aggregate data, to export in one or several files, etc. The default configuration will export an excel file that enables the user to easily create a pivot table containing all KPIs values from the current study.

Future modules (description in a later version of this document) include:

- | Gas market
- | Demand
- | Heat
- | Distribution networks
- | Capacity expansion

3. CONCEPTS USED IN ARTELYS CRYSTAL SUPERGRID PLATFORM

In this section, various concepts and definitions on the modelling of energy systems with ACSG Platform are introduced.

An energy system is defined by its energies, its assets – may they be energy production or energy consumption assets – and the elements that connect them.

3.1. ENERGIES AND OTHER TRADED COMMODITIES

An energy system tool requires to model energy vectors in terms of production, consumption and exchanges. These energy vectors (such as **power, gas, heat, cooling**, etc.) are represented as **energies**. Energies are commodities which can be produced, consumed and exchanged.

As such, **energies** do not only cover classic energy vectors but also other traded commodities such as **CO₂ emissions** or **water**.

Throughout this document, all the aforementioned quantities may be simply referred to as energies.

3.2. ASSETS, ASSET TYPES AND ASSET MODELS

Any production and/or consumption unit or cluster will be represented by a so-called **asset** in the energy system model.

For instance, wind power plants, gas power plants and power transmission lines are all “**physical assets**” that are included to model power production and transmission. These assets will typically be referred to as **power production assets** and **transmission assets**. Note that, like gas power plants which are power production assets and also gas consumption assets, some assets can be **multi-energy** assets.

Consumer demand, supply contracts, CO₂ emissions and loss of load can be modelled by so-called “**financial assets**”. In the ACSG Platform Graphical User Interface, these non-physical assets differ from previously described **physical assets** by their shape and colour.

The METIS configuration offers a **library of asset types** (see the technical documentation on Assets) to model the corresponding assets in the energy system. For example, all nuclear fleets are modelled with assets of the same ‘nuclear fleet’-type. As such, an asset is an instance of an **asset type**.

Each asset type is defined by an **asset model** and a set of parameters. The asset model defines how an asset of this type will consume and/or produce energies. The parameters are the input data to the asset model. For instance, the installed generation capacity and the efficiency rate can be such parameters.

3.3. ENERGY ZONES AND DELIVERY POINTS

In ACSG Platform, geographic regions are represented with **energy zones**. Depending on the case study, energy zones can cover a country, an aggregation of countries or smaller regions (for instance NUTS2 regions).

Two energy zones can cover the same spatial entity but for different energies. For example, in a gas and heat model for Estonia, ‘Estonia_gas’ and ‘Estonia_heat’ energy zones will be created, each one allowing the creation of gas (or respectively heat) production, consumption and transmission assets. Indeed, assets consuming or producing a given energy has to be in a corresponding energy zone.

Assets can be in more than one energy zone at the same time. For instance, CCGT assets consume gas, generate electricity and emit CO₂. As such they are in the gas energy zone, power energy zone and CO₂ energy zone.

In each energy zone exists a **delivery point** which connects the assets producing, consuming or transmitting this energy, so that the energy respect a supply/demand equilibrium (or equivalently, Kirchhoff's first law).

Delivery points are defined by a name and a geographic location on the map (longitude and latitude). For instance, the "Estonia_gas" energy zone has a delivery point in its centre called Estonia_gas. Such delivery points are often called primary delivery points and represent exchanges between all actors for a given energy in a given zone.

Other delivery points can be created for asset modelling purposes. These so-called **intermediate delivery points** usually connect two specific assets or contracts together, and as such do not represent exchanges between *all* actors in a zone, although they also guarantee a local supply-offer equilibrium between the assets connected to the delivery point.

3.4. MULTI-ENERGY SYSTEM

A **multi-energy system** is a system in which various energies are exchanged between multi-energy assets. It is defined by the energies exchanged, a set of multi-energy assets, a set of energy zones and the corresponding delivery points that connect these assets, and the connections between assets and delivery points.

3.5. HORIZONS

An energy system is usually managed or assessed over a certain period of time between specific dates, depending on the purpose of the considered study. These time specifications are referred to as the **horizon** or **strategic horizon**. Additionally, a key characteristics of a study is the **time step duration**, i.e. the time granularity of the simulations performed.

The METIS configuration is usually used to assess the costs of the system over a year, at an hourly time step, i.e. for 8760 hours.

3.6. CONTEXTS AND STUDIES

What is referred to as **context** is a model of an energy system and its data. A **context** contains **energy zones** and **assets** inside them, along with their parametrization.

For instance, the user can create a **context** whose name is EUCO30_2030 corresponding to the power system of the full EU28 + 6 non-EU countries, whose parameters (installed capacities, consumption levels, prices) correspond to the 2030 point of the European Commission EUCO30 scenario.

Assess the interest of a given asset whose lifetime is long, such as an interconnection project, often requires studying the asset under different long-term situations and thus performing simulations for different contexts (e.g. a context based on EUCO30 data and one based on EC Reference scenario data). These contexts can be regrouped in the same **study** (i.e. a set of contexts sharing the same strategic horizon).

3.7. TEST CASES AND RANDOM DATA

The analysis of an energy system often requires considering the same system in different shorter-term situations. For instance, even in a same context, i.e. in the same general assumptions of power mix and energy efficiency, it is often key to look at the energy system management under several weather variations (which impact notably consumption and renewable generation profiles).

These weather variations are included in "**test cases**", each one containing a set of profiles corresponding to a given weather year.

More generally a parameter of an asset is said to be represented by a "**random data**" when it varies depending on the test case. For instance, when test cases represent weather, RES load factors and consumption profiles are all "**random data**".

3.8. SCENARIOS

Artelys consultants will provide so-called **scenarios** to create studies and their contexts using selection and aggregation scripts. These scenarios or reference data sets will be populated with data for a given horizon (typically 2030 or 2050) and supply mix. It is not to be confused with a context. A scenario can lead to multiple contexts depending on the applied selection and aggregation scripts.

A scenario is stored in a reference data set which is a set of Excel and csv files. As such, it can be viewed and edited by developers. Hence, developers will be able to create new scenarios if they wish to do so. However, it is not intended to be manipulated by analysts and decision makers who will use them as starting points to their studies and directly through the software application.

A scenario has the following properties:

- | It is characterized by its system and network data, including random values such as availabilities and load factors;
- | It is referenced by its name;
- | It can be imported into the Crystal platform;

4. USER TYPES

The Artelys Crystal Super Grid Platform can be quickly customized by Artelys experts to adapt to different types of users.

This enables each type of users to focus on his own questions and make maximum benefits from METIS models.

4.1.1. DECISION MAKERS

METIS can be used very simply by decision makers to analyse results of existing studies and scenarios by looking at several key indicators on the map or in synthetic graphs.

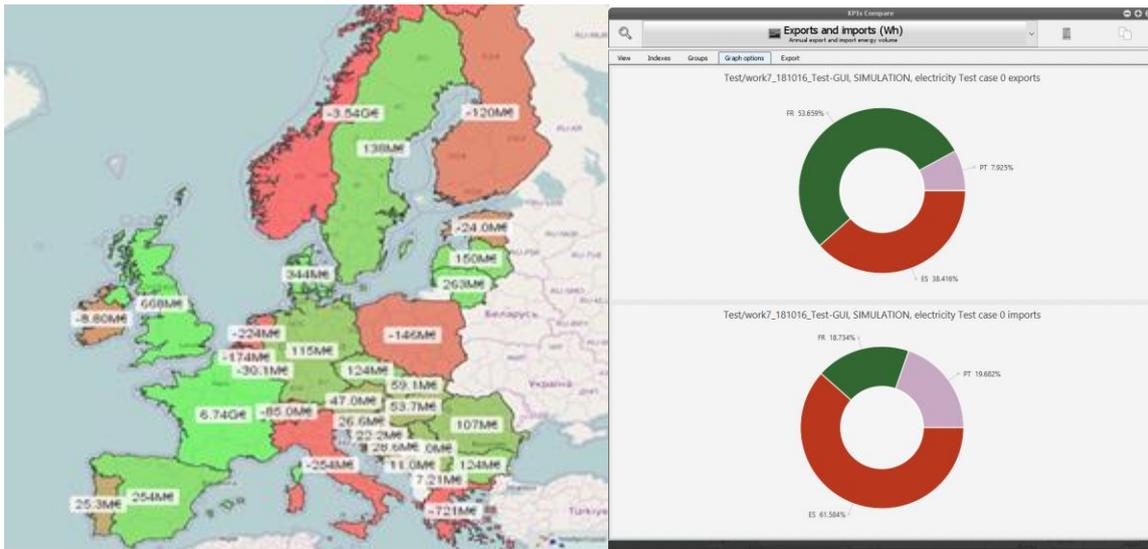


Figure 2. Example of results display – Map View and KPI View

4.1.2. ANALYSTS

Analysts can create studies as variants of the provided scenarios. Modifying context data such as assets parameters can be done in the interface, with user-friendly views.

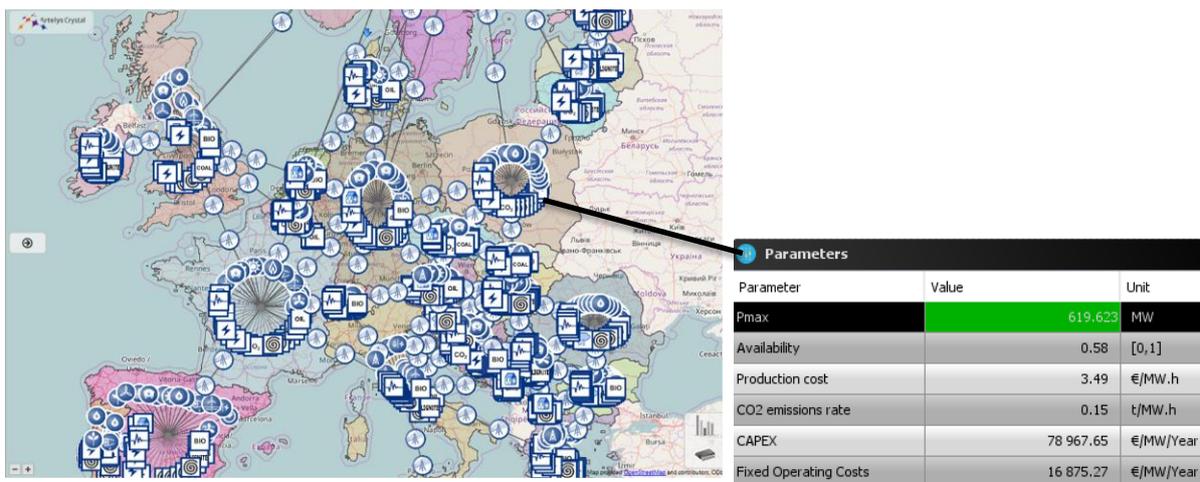


Figure 3. Modifying context data in the interface

In particular, analyst users can:

- | Choose the level of details in the model, for example activate / deactivate reserve,
- | Launch simulations with a simple click and run on a laptop,

- | Analyse results in details using more than 60 indicators and detailed time series displayed in custom graphs.

Detailed documentation on models, scenarios and KPIS is available for analysts.

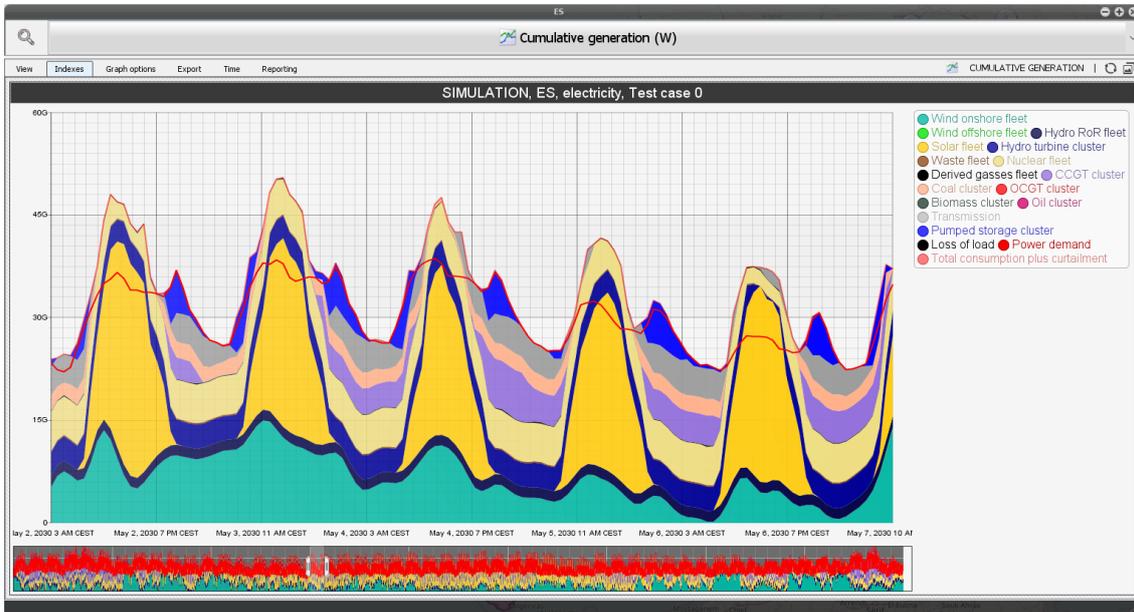


Figure 4. Example of results display - Cumulative Generation Curve

4.1.3. DEVELOPERS

Developers are granted access to all of the previous features and can also:

- | Create their own scenarios by adding files to the database and creating import scripts,
- | Modify the configuration files (Jython code) to enrich and adapt views and indicators using the dedicated API,
- | Implements new models to extend the asset library.

Detailed documentation on delivered scripts, the database, the scripting API and the modelling API is available for developers.

```
<AssetModel name="Lignite supply" label="Lignite supply" picture="pictures/Lignite supply.png" type="financial" tags="PRODUCTION_CONTRACT">
  <EnergyDelivery name="E" default="lignite" unit="@ENERHEATVALUE"/>
  <AssetData id="_price" type="Double" default="30" show="true" editable="true" label="Price" unit="@CURRENCY/@ENERHEATVALUE"/>
  <Models>
    <Model id= "Full">
      <![CDATA[
stateON = AssetState('ON')
addEnergyCost(stateON, asset.getParameter('E'), False, asset.getData('_price'))
MODEL.addState(stateON)
]]>
    </Model>
  </Models>
</AssetModel>
```

Figure 5. XML Asset File

5. DOCUMENTATION LIST

Document	Contents
METIS Software Introduction	Presentation of METIS, what it can be used for, its architecture and the main concepts used in it
METIS Quick User Guide	Description of how to use the METIS Software (slides)
METIS Training Manuals	Tutorials for METIS Power System Module (1 document) and for METIS Power Market Module (1 document)
METIS Model Documentation	Description of the equations/models, assets, data for each module. 1 document per module (Power System Module, Gas System Module, Power Market Module)
METIS Data	Integration of PRIMES scenarios into METIS (1document) Market Module Configuration for S12 Study (1 document)
Detailed Description (automatically generated html file)	Description of KPIs and Decorators Description of each asset's parameters and constraints

