



# Best practice for performing case studies for the European energy system in transition

DELIVERABLE D6.3



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## Executive Summary

Open ENTRANCE has developed an open-source modelling platform that:

- Allows carrying out scientific calculations and assessments for different future options of a low-carbon Europe.
- Makes models relevant for analysing different aspects of the energy transition open available, e.g. energy system models, macro-economic models, etc.
- Makes data to be used in energy transition analyses open available, like energy system data, human behavioural data (e.g. energy consumption habits), macro-economic data, etc.
- Soft links models such that output from one model can be used as input to another model and in that way provide consistent analyses across models.
- Supports stakeholders to determine consequences of the energy transition and identify the best ways to transition to a 'low-carbon' economy.
- Is openly available to use by any interested users, targeting mainly researchers and modellers.

9 case studies have been performed during the project, as a real-size proof of concept of the project, applied to the main topics of the energy transition. These case studies made extensive use of the Open ENTRANCE platform

The objective of this report is mainly to help future users of the platform to make the best use of it, as well as to give them some advice coming from the experience of the case studies.

Conducting case studies via the Open ENTRANCE platform allows to:

- Elaborate deeper analysis of the Open ENTRANCE scenarios thanks to the possibility of running specialised models fed with the Open ENTRANCE scenario results, including power system models, local models....
- Benchmark results of different models (eg. 2 different power system models, 2 different macro economic models, 2 different energy system models) and easily compare them. This also increases confidence in the results;
- Increase confidence of all results thanks to the full transparency of data, assumptions, algorithms and results;
- Showcase analyses by taking advantage of the postprocessing and visualisation functions available in the Open ENTRANCE platform;
- Make all results easily re-useable.

The first part of this report includes a tutorial designed to help users to conduct a case study within the Open ENTRANCE environment, in particular how to define a case study workflow, how to describe the data involved in this workflow using the Open ENTRANCE nomenclature, how to download data from the platform, how to create linkage scripts for soft-connection of models to the platform and how to create datasets and upload them to the platform. The second part is devoted to advice from experience within the 9 case studies.



# 1. Introduction

## 1.1 Project Summary

The EU has set the ambition to reduce greenhouse gas emissions to the point of becoming climate neutral by 2050 and prevent the negative and irreversible effects of climate change. This goal includes shifting the energy system to a renewable and clean supply, as well as technological, behavioural and organisational changes in the economy and society. For doing so, the coordination of relevant technologic solutions, policies, funding and actors, with well-defined targets based on scientific analyses will be required.

In response, Open ENTRANCE has developed an open-source modelling platform that:

- Allows carrying out scientific calculations and assessments for different future options of a low-carbon Europe.
- Makes models relevant for analysing different aspects of the energy transition open available, e.g. energy system models, macro-economic models, etc.
- Makes data to be used in energy transition analyses open available, like energy system data, human behavioural data (e.g. energy consumption habits), macro-economic data, etc.
- Soft links models such that output from one model can be used as input to another model and in that way provide consistent analyses across models.
- Supports stakeholders to determine consequences of the energy transition and identify the best ways to transition to a 'low-carbon' economy.
- Is openly available to use by any interested users, targeting mainly researchers and modellers.

This open platform has been demonstrated by carrying out case study simulations covering different key aspects of the energy transition in Europe, based on the targets for the EU Energy Union.

## 1.2 Summary of case studies

The main objectives of the case studies were:

- Show the adequacy and relevance of the Open ENTRANCE platform. For this purpose, the case studies have been using scenarios, assumptions and data developed within [D7.1], [D3.1] and [D3.2], and the suite of modelling tools [D5.2]
- Show the ability of the proposed approach to answer specific questions related to the evolution of the energy system. This has been done with a specific focus on the effects of decentralisation, variability, the need for flexibility, real market functioning, integration of energy sectors, behaviour of individuals and communities of actors.
- Provide complementary inputs (data) to Scenario Exercises. This has taken place during the process of running the case studies, which conducted to a new version of the Scenarios in [D3.2]

In order to perform the case studies, simulations were run using the linked models described in [D5.2] and the scenario dataset developed in [D3.2]. As for the dataset, in order to ensure consistency among studies, supplemental data, which were needed on specific items, were added while performing the case studies.

Therefore, it will be possible to easily re-run case studies or derive variants or challenge them by using other models/data.

Regarding the linkage of the data and models, it relied on the common Open ENTRANCE data format (see [D4.2]) as well as on the nomenclature which is defining the variables and regions names, as well as establishing rules for using them (see the open repository [Nomenclature] ), and [D5.4] for a detailed description of its organisation.

Models are ‘soft-linked’ (see [D5.2] ) to the Open ENTRANCE platform, which means that either they are internally using the Open ENTRANCE data format, or scripts are available which convert the models data format to the Open ENTRANCE data format.

The case studies are the following:

- Case study 1 is dedicated to Demand-Response from household consumers. It evaluates the flexibility potential when using load-control with household consumers and study its impact on the integrated European electricity system cost, operation and investments needs.
- Case study 2 is dedicated to behaviour of communities of actors. It studies shared energy management in different local energy community concepts, taking into account the individual preferences of the actors involved. Based on comprehensive modelling, the quantitative results have been up-scaled on country and European level.
- Case study 3 is dedicated to the analysis of the balance of flexibility to be provided across storage and transmission technologies. It analyses how the use of flexible hydropower, transmission, and, more generally, of different kinds of storage (pumped-hydro, batteries,...) can tackle some of the main challenges of the energy transition..
- Case study 4 is dedicated to cross-sector integration, with a specific focus on the flexibilities provided by electric vehicle owners to the electricity system. It also evaluates the impact of import hydrogen prices on the integrated system.
- Case study 5 compares different levels of geographic coordination for investment decisions, both at regional and European level, focusing on the topic of decentralisation. In particular regional decisions with local objectives were compared with European coordinated decisions with global targets.
- Case study 6 analyses the use of innovative technology in terms of underground rocks for seasonal storage of heat from summer to winter in a district in Oslo, Norway. The analyses show the impact on the energy system in the district.
- Case study 7 evaluates the impact of flexibility from electrified heating on the Danish power system.
- Case study 8 investigates the role of natural gas storage in current and future energy systems in Turkey.
- Case study 9 analyses the effects of different types of barriers, from political to technological, to the energy mix, on the sectoral activities, and on the economic growth of the European countries.

### 1.3 The Open ENTRANCE platform

Open ENTRANCE has developed the Open Energy Platform (see [platform] ), which is accessible via <https://openenergymodels.net> and will be maintained beyond the project duration.



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This platform includes links to everything that is necessary to perform a case study within the Open ENTRANCE environment:

- All public project data are accessible via the IIASA Scenario Explorer. This database can further be enriched by new data coming from future work relevant to the scope of open ENTRANCE;
- Data format: Open ENTRANCE has developed a common data format based on the IAMC data format. The description of this data format is available on the platform
- Models: different energy models are soft linked in the Open ENTRANCE project. Those models, including all information how to use them are available on the platform
- Tools for data processing (including the nomenclature of variables, regions and time slices), transformation, aggregation, visualisation, etc.
- Case study reports.

## 1.4 Objective and scope of this deliverable

The objective of this deliverable is to help future case studies to be conducted in the Open ENTRANCE environment.

Section 2 includes a tutorial designed to help users to conduct a case study within the Open ENTRANCE environment, in particular how to define a case study workflow, how to describe the data involved in this workflow using the Open ENTRANCE nomenclature, how to download data from the platform, how to create linkage scripts for soft-connection of models to the platform and how to create datasets and upload them to the platform.

Section 3 includes advices derived from the experiences of the 9 case studies which were already conducted.

## 2. How to use the open platform

The objective of this section is to serve as a tutorial for users wishing to conduct a case study using the models, tools and data available on the Open ENTRANCE platform.

Conducting a case study requires to follow the different steps below:

1. Define your case study and chose the models you need to use. This is independent of the Open ENTRANCE platform. However, if the model(s) to be used is (are) already « linked » to the Open ENTRANCE platform, users may take advantage of the different tools that are made available for the model(s). Recall that models (see list in previous section) are ‘soft-linked’ to the Open ENTRANCE platform, which means that either they are internally using the Open ENTRANCE data format, or scripts are available which convert the models data format to the Open ENTRANCE data format.

The following steps are further detailed in next sub-sections.

2. Define case study workflow
3. Define detailed data workflow
4. Define lists of individual data and match them with the variables in Open ENTRANCE nomenclature ; If necessary, propose extensions to the nomenclature.
5. Create Model(s) input dataset
6. Run Models
7. Upload results to the Open ENTRANCE platform

### 2.1 Defining the case study workflow

#### General workflow

The first step of a case study analysis, once its framework has been defined, is to identify the global data workflow, in particular in the case where different models are used. The workflow will identify the main exchanges between the platform and the models as well as among the different models.

The workflows of the 9 case studies conducted in Open ENTRANCE have been defined and are described in details in D5.2. We give below 2 examples of general workflows defined for case studies with more than one model involved.

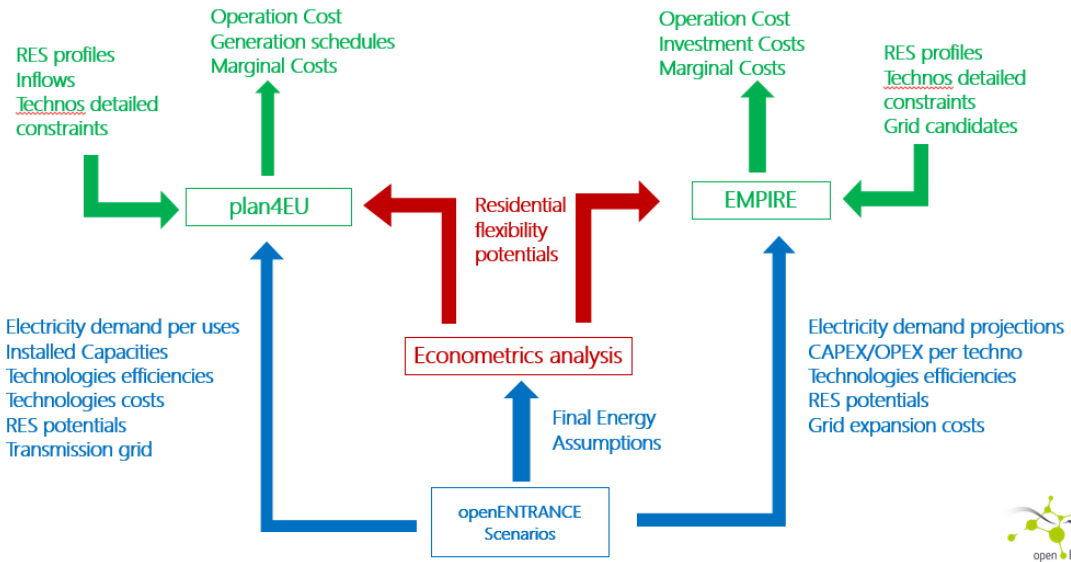


Figure 1: General workflow of Case study 1

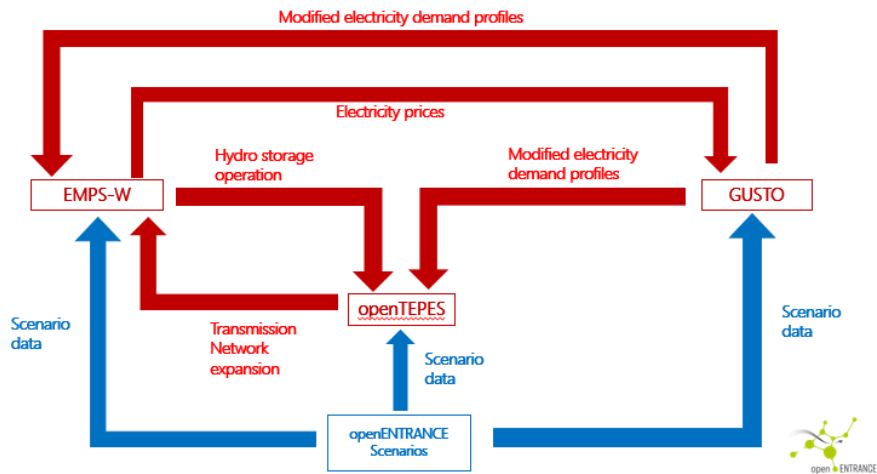


Figure 2: general workflow of case study 3

In Figure 2 and Figure 1, we can see that different ‘groups’ of data are defined depending on the origin and destination of those data:

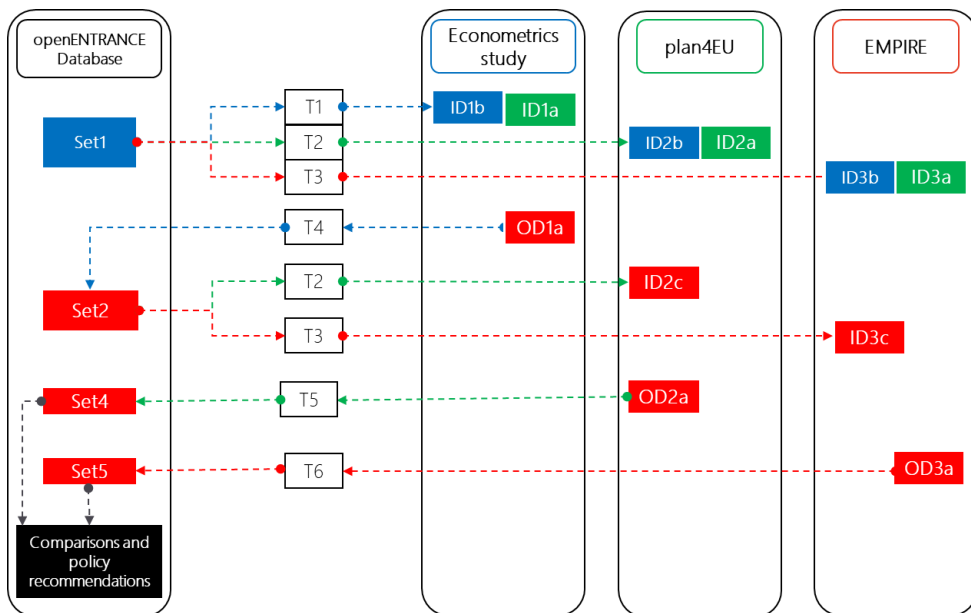
- **Data in blue** are taken from the Open ENTRANCE scenarios (see [D3.2])
- **Data in green** are additional data coming from Models own databases (or other sources)
- **Data in red** are exchanged between models.

**Detailed workflow**

Once this high-level workflow is defined, one need to identify the very accurate list of data that are part of each ‘group’, and in particular:

- the data which are common input to more than one model
- the data that are specific input to one model,
- the data that are output of one model and becoming input of another model
- the models input data that will be uploaded to the platform. Note that not all models input are usually uploaded to the platform. In particular, some models may uses very volumetric inputs, such as scenarized hourly timeseries over many years, that would be difficult to upload. Also some inputs may be already present on the platform. In general, data which may be interesting for further uses should be uploaded.
- the models outputs that are worth uploading to the platform (worth meaning these outputs may be useful for further use, or to understand results presented in a report...)
- ....

For this we define a detailed workflow as shown in the 2 examples below, also deriving from case studies 1 and 3.



**Figure 3: Open ENTRANCE case study 1 detailed workflow**

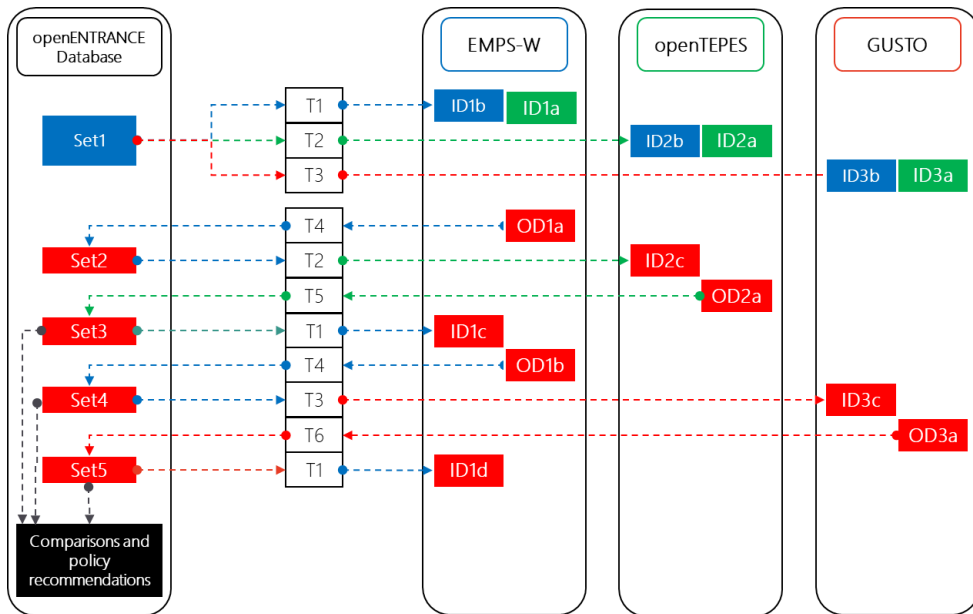


Figure 4: Open ENTRANCE case study 3 detailed workflow

In Figure 3 and Figure 4 we can visualise the different groups of data as well as the transformation which are conducted on those data :

- The same color codes are used for boxes (Blue : data from scenarios, Green : data from own model database, Red : exchanged data) ; The colors of the arrow are defined by the model they are relating to (blue : econometric study / EMPS-W, green : openTEPES/ plan4EU, red : GUSTO/EMPIRE)
- Set1 is the dataset comprising all the data which are taken from the Open ENTRANCE scenarios, without transformation. These data are then transformed into the format/granularity/resolution required by each model. For this, linkage tools are required (denoted T1, T2, T3 in the examples). Datasets ID1b, ID2b and ID3b are then created. Those dataset still only comprise data from the Open ENTRANCE scenarios, but after some transformations.
- ID1b, ID2b and ID3b may not be including all the data required by the models. These dataset are then enriched by data coming from the models own database (or other model-related sources), denoted ID1a, ID2a and ID3a in both examples. In summary, in Figure 3, ID3b+ID3a is the complete input dataset required by the EMPIRE model for a reference run.
- Model runs are producing output data. Those may be either transformed and uploaded to the Open ENTRANCE platform (either for storing them for further uses, or because they are going to be used by another model within the study, via the platform), or transformed and used as input by another model (in some cases with very high volumes of data, it may be difficult to upload to platform and then allow the second team to download – in that case it is highly recommended to proceed to the exercise with a subset of data in order to validate and check the data) . An example

is shown in Figure 4 where OD1a is an output of the EMPS-W model. It is transformed into ‘Set 2’ (for upload to the platform) by using tool T4, then in ID2c (openTEPES input). openTEPES can then be run with ‘ID2a+ID2b+ID2c’ as an input dataset and will create OD2a as an output (which can also be transformed, uploaded or not to the platform, and used by EMPS-W as an additional input)

Note that the data format of Pack#i/Set#i data has to be according to the Open ENTRANCE data format (see [D4.2]), while ID#i#x and OD#i#x are datasets within the native input/output data format of the respective models.

Also note that it is warmly advised that data which are going to be exchanged between models are following the Open ENTRANCE format, as this is a very good way of preventing mistakes. It is also recommended that in the case of reasonable volumes of data, the exchanges are made via the Open ENTRANCE platform, and in the cases where the volumes of data are too big, at least a subset of (if possible representative) data is exchanged via the platform.

## 2.2 Describing the data (input and output of all models involved)

The objective of this set is to define an accurate description of every single data belonging to every group of data which may be exchanged between models or between one model and the Open ENTRANCE platform. This will be done using the variable and regions nomenclature which is described in [D5.4] . Using this nomenclature has proved efficient to prevent misunderstandings and mistakes related to what the data really is.

As seen in [D4.2], each data are defined by :

- A model name (the name of the model used to create the data)
- A scenario name (the name of the scenario run we are going to use)
- A region name (note that this can also represent an interconnection between 2 regions)
- A variable name
- A time period (eg. 2050, or January 12, 2034, 10 :00 to 14 :00) ; representative time periods can also be defined (eg a representative -under specific criteria- week per season in 2045)

Variable names, as well as region names and subannual time slices must be non-ambiguous. For this, they are defined in the Open ENTRANCE nomenclature (see [Nomenclature] and [D5.4] ). It is necessary to dive into this nomenclature before establishing the list of data.

The list of models, scenarios, variables, regions for which some data exist in the [ScenarioExplorer] can be seen in the ‘Documentation’ section of the [ScenarioExplorer].

Note that if a new region/variable/subannual slice is needed, it has to be defined in the nomenclature first. The nomenclature is available on Github under an open-source license to facilitate reuse by other projects. Adding a new variable/region/time slice is very easy and requires only beginner use of Github (edit a text file, commit your change, create a « pull request » to « request » your change to be included in the nomenclature).

Below is, as an example, the detailed list of variables which are included in the Pack 1 of Case study 1 (ie. Data from the Open ENTRANCE scenarios which are used by the model plan4EU):





- Model(s): GENeSYS-MOD 3.1
- Scenario(s) : Techno-Friendly 2.0
- Region(s) : Europe (incl. Turkey), Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Non-EU-Balkans, North Macedonia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, The Netherlands, Turkey, United Kingdom, as well as all interconnections between those regions (Region1>Region2)
- Time slice(s) :2050
- Variable(s):
  - o Final Energy|Electricity
  - o Final Energy|Electricity|Heat
  - o Final Energy|Electricity|Transportation
  - o Network|Electricity|Maximum Flow
  - o Capacity|Electricity|<Electricity Techno>
  - o Variable Cost (incl. Fuel Cost)|Electricity|<Electricity Techno>
  - o Fixed Cost|Electricity|<Electricity Techno>
  - o Capital Cost|Electricity|<Electricity Techno>

Where <Electricity Techno>={ Biomass|w/CCS, Biomass|w/o CCS, Coal|Hard coal|w/o CCS, Coal|Hard coal|w/CCS, Coal|Lignite|w/o CCS, Gas|CCGT|w/o CCS, Gas|CCGT|w/CCS, Gas|OCGT|w/o CCS, Geothermal, Hydrogen|OCGT, Nuclear, Oil|w/o CCS, Hydro|Reservoir, Hydro|Pumped Storage, Hydro|Run of River, Solar|PV, Wind|Onshore, Wind|Offshore }

- o Secondary Energy|Electricity|Hydro|Reservoir
- o Secondary Energy|Electricity|Solar|PV
- o Secondary Energy|Electricity|Wind|Offshore
- o Secondary Energy|Electricity|Wind|Onshore
- o Secondary Energy|Electricity|Hydro|Run of River
- o Maximum Storage|Electricity|Hydro|Pumped Storage
- o Pumping Efficiency|Electricity|Hydro|Pumped Storage
- o Maximum Storage|Electricity|Battery|Lithium-Ion
- o Maximum Charge|Electricity|Battery|Lithium-Ion
- o Roundtrip Efficiency|Electricity|Battery|Lithium-Ion
- o Maximum Storage|Electricity|Compressed Air'
- o Maximum Charge|Electricity|Compressed Air'
- o Roundtrip Efficiency|Electricity|Compressed Air'

## 2.3 Downloading data from the Open ENTRANCE platform

Retrieving data from the Open ENTRANCE platform, once the list of data to be downloaded is defined, may be done in 3 ways:

- From the [ScenarioExplorer] website: connect as guest, create your own workspace in which you can select from the list of scenarios, regions, variables, time ranges and time slices which are available on the platform. Once you have selected your data, you may access simple visualization tools, as well as download the selected data.

- Some pre-treated datasets are available in the Download section of the [ScenarioExplorer], in particular the Open ENTRANCE scenarios as well as the results from the macro-economic study and the case studies.
- Use the pyam package which allows you to directly import your data within python. In this way the data download can be included in the linkage scripts of models (see next section).

## 2.4 Implementing linkage scripts

Each model can be ‘soft-linked’ to the Open ENTRANCE database (the Scenario Explorer, see [ScenarioExplorer]) by linkage scripts implemented in python. The pyam package (see [pyam] for extended documentation, API and tutorials) includes many functions that can be used in the scripts, both for connection to the platform (in particular for downloading data, checking that a dataset is consistent with the Open ENTRANCE nomenclature, treating data -aggregations, .....- and visualising them). For each model, 2 main linkage scripts are required :

- ❑ **« Input » linkage script:** this script will be used to download the required data from the Open ENTRANCE platform (and if necessary from other sources), to proceed to required data transformation, and to create the Models input dataset in the model’s native data format.
- ❑ **« Output » linkage script:** this script will be used to post-treat the native model’s output data, in particular proceed to the required transformations of data and convert the required model’s output to the Open ENTRANCE format, as well as check that this later dataset is valid for upload to the Open ENTRANCE platform.

Standard linkage scripts for every open model linked to the Open ENTRANCE platform are available on the platform (see [linkages]).

In the following sub-section we detail some of the functions that are used in the scripts.

### Connect to platform

`pyam.iiasa.set_config(cfg['user'],cfg['password'])` : this allows the user to input its credentials (if any)

`pyam.iiasa.Connection('openentrance')` : this creates a connection to the Open ENTRANCE Scenario explorer database, in which most project data are stored

### Download data and Create an IamDataFrame

IamDataFrame is an object defined in the pyam package (see [The IamDataFrame class — pyam 1.9.0 documentation \(pyam-iamc.readthedocs.io\)](#)), which derives from the well known DataFrame (from the pandas package) and offers a set of additional features, adapted to the Open ENTRANCE data format.

`DownloadedData = pyam.read_iiasa('openentrance',model='GENeSYS-MOD 3.1', variable=['Capacity|Electricity|Nuclear', 'Secondary Energy|Electricity|Hydro|Pumped Storage], region=['France','Germany'],year=[2050], scenario='Techno Friendly 2.0')` : this creates an IamDataFrame object which contains the data corresponding to the selection (here data generated by GENeSYS-MOD 3.1 in its ‘Techno Friendly 2.0 run, in which we selected 2 variables, 2 regions and the year 2050

### **Convert Units**

`ConvertedData = DownloadedData.convert_unit('EJ/yr', to='MWh/yr')` : this is used to convert some data to another unit. In case the conversion is not between well-defined SI units, the user can specify a custom conversion factor.

### **Aggregate some regions and filter**

`AggregatedData=DownloadedData.aggregate_region(region='Scandinavia', subregions=['Norway','Sweden','Finland','Denmark'],append=True)` : this is used to aggregate all the variables defined for the selected countries. Within the nomenclature, the region 'Scandinavia' was previously defined as corresponding to the aggregate of the 4 countries selected here.

`FilteredData = AggregatedData.filter(region='Scandinavia')` : this allows to only keep the data corresponding to the selected region(s)

- `df.convert_unit().timeseries()`
- `df.multiply().timeseries()`

### **Change subannual format**

If subannual timeseries are included in the `IamDataFrame`, it may be necessary to adapt the format by using the following function :

`OutputDF.swap_time_for_year(subannual=True)`

### **Check that the dataset is correct**

`FilteredData.validate()` : this function performs a series of tests to check consistency of the data to the Open ENTRANCE nomenclature. These tests are also performed when uploading data to the platform, but checking before trying uploading the data set has proven to be more efficient.

### **Create xlsx files for upload to database**

`OutputDF.to_excel(myDir, sheet_name='data', iamc_index=False, include_meta=True)` : this function will create an excel file which can be uploaded to the platform (ie containing a sheet with data in IAMC format plus a metadata sheet)

The model and scenario names are not checked by the validate function. Nevertheless, it is only possible to upload data for 'registered' models (see the list of registered models in the documentation section of the Scenario Explorer). If a model is not registered, the Scenario Explorer administration team must be contacted to register this model. Regarding the scenario name, no controls are done. Nevertheless, the scenario name shall be chosen with great attention. If a dataset based on one of the 4 Open Entrance

scenarios is created, the latter should be included in your Scenario name, as well as, possibly, a description of the scenario. Model names should never be included. Examples are given below:

- Techno Friendly 2.0|Residential Load Control|2020 potentials|Realistic Flexibility
- Techno Friendly 2.0|Residential Load Control|2020 potentials|Full Flexibility
- Techno Friendly 2.0| HIGH\_XB\_HIGH\_EV\_HIGH\_H2| NO\_EV\_FLEX
- Techno Friendly 2.0| HIGH\_XB\_HIGH\_EV\_HIGH\_H2| FULL\_EV\_FLEX

## 2.5 Installing and running models

Within the Open Energy Models platform (see [platform]), energy models are available. The modelling suite covers the many dimensions of the energy transition and allows users to carry out integrated analyses that go beyond the scope of each model offers separately.

There are both macro-economic models (REMES and EXIOMOD), multi-energy-carrier models (GUSTO, and GENESYS-MOD) and models focused on the electricity sector (EMPIRE, OPENTEPES, PLAN4EU, FRESH:COM). Most of the models can cover the entire EU, while some are focused on local energy needs (GUSTO, and FRESH:COM). The majority of the open energy models deal with the planning of the expansion and operation of the system, while GUSTO and FRESH:COM are focused on the operation.

The [platform] offers links to all the models in the suite, as well as their user guides, including tutorials how to download/install/run the models, depending on specific model licence/condition.

The following models are available:

- [GENeSYS-MOD, TU Berlin](#): Cost-optimising linear program, focusing on long-term developments of the energy system, with a detailed approach to sector coupling of the sectors electricity, heat, and transportation.
- [EMPIRE, NTNU/SINTEF](#): Infrastructure Investment under varying and uncertain loads.
- [REMES-EU, NTNU](#): a multi-regional, multi-sectoral Computable General Equilibrium model designed primarily to analyse the impacts of different climate policy measures and the interactions between the economies of the European Countries.
- [EXIOMOD 2.0, TNO](#): Multisector, multi-region, computational general equilibrium model that is able to measure the environmental and economic impacts of policies, considering variables such as GDP (Gross Domestic Product), value-added, turn-over, consumption, investment, employment, trade (exports and imports), public spending or taxes.
- [openTEPES, Comillas](#): Electricity network modelling and analysis of the impact of the implementation of specific energy policies on the development of the transmission network.
- [Plan4EU modelling suite, EDF/plan4res H2020 project](#): Focused on the electricity system, comprises a capacity expansion model which finds the optimum compromise between generation/storage investment and transmission/distribution expansion for a given long-term horizon; as well as a seasonal storage valuation tool; and a European operational dispatch model.
- [FRESH:COM \(Fair Energy SHaring in Local COMMunities\), TU Wien](#): Multi-objective optimization tool for optimal local renewable technology portfolio dimensioning/design and consideration of the individual actors' sharing allocation preferences in different local energy community configurations.

- [Gusto, TU Wien](#): Optimal utilization of small battery storages and flexible loads on prosumer level under various operation strategies.

## 2.6 Uploading relevant data to Open Entrance Scenario Explorer

### Uploading the data

Once an excel file has been created (see Create xlsx files for upload to database), the last step is to proceed to its upload to the [ScenarioExplorer]. This is not possible via a ‚guest‘ connection, which means you need to first require credentials via the ‚register‘ button of the main page.

Once you are registered and logged-in, uploading your data becomes possible via your user space in which an upload facility is accessible. You then will have to select your excel file, describe it and proceed to the upload. In case the file is not fulfilling all the Scenario explorer requirements, the list of errors will be accessible. Most of the errors can be avoided by first validating the data (see previous sections).

### Creating a workspace

Once data is uploaded to the scenario explorer, it becomes possible to create a Workspace in which those new data may be made accessible following the same procedure as in section 2.3.

### Making data public

The data can be made public either by making public the workspace in which the data are accessible, or via a link in the ‚download‘ section of the [ScenarioExplorer]. The latter can only be done by the scenario explorer administration team, and first requires your dataset to be uploaded to a public repository, including description of metadata and documentation of the study. Zenodo is the recommended repository for Open ENTRANCE.

# 3. Lessons learnt, advices and best practices

Within Open ENTRANCE, 9 case studies have been conducted which implemented all or some of the steps described in chapter 2. These experiences allow us to propose a set of advices for best use of the Open ENTRANCE platform.

## 3.1 Data preparation

Data preparation takes longer time using the Open ENTRANCE common data format than using custom-made data formats. However, teams working on most case studies acknowledged that the common data format has proven to be useful, as it has a very clear structure, which makes the benefit of using it greater than the cost of transforming the data format.

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## 3.2 “Case examples”

Within the process of undertaking the case studies, all teams were asked to create small representative examples of the case studies once the workflow had been defined, using exemplary data. This step proved efficient and made it easier to stay on schedule for the case study and helped to produce results in a timely manner.

## 3.3 Graphs

Collaboration with other case studies to create similar looking figures and charts would have been desirable, for example, in the form of a shared repository on GitHub. This could not be done during the Open ENTRANCE project but could be included in further projects. Moreover, some of the “linkage” scripts did include visualisation functions which are available on the project repository and can be reused in future studies.

## 3.4 Big data

Some of the models used are very detailed, both regarding time and geographic granularity, but also as they include accurate modelling of the system. Also, some of the models are stochastic which means that they are using a number of scenarized timeseries as inputs and produce a number of scenarized timeseries as outputs.

Although the Open ENTRANCE data format makes it possible to include scenarized and subannual data, the size of input or output datasets may become very big, and thus the Scenario Explorer may seem less adapted. The Scenario Explorer allows upload and download of subannual data (including a variety of synthetic ways of representing those data, such as representative or average weeks per seasons for example), but it does not yet allow to visualize subannual time series.

The experience of case studies including such models and dataset made us formulate the following advices for the cases including huge datasets, and potentially use of more than one model:

- It is essential to use the Open ENTRANCE data format and nomenclature and validate the datasets using the validation functions available within the nomenclature as this prevents most errors.
- It proved very efficient to demonstrate data exchanges via the Scenario explorer, at least for a subset of data including all different variables, regions, subannual ranges which may exist in the final datasets.
- Exchanges of data among models can then be made effective via usual ways of exchanging huge datasets, the step below ensuring that data are valid.
- Not all data can be included in a workspace (in particular subannual data), as the functionality for easy selection of subannual ranges is not yet implemented. Nevertheless it is possible to upload all of the data (inputs and outputs) to the platform, so that users can easily access to the list of available variables, regions, time ranges.

## 3.5 Multiple models linkages

Some difficulties arose in those case studies involving the use of more than one model as well as the embedded use of the models, in particular in CS3 and CS9 in which an iterative process involving many models runs was implemented:

### Harmonization of data

- In Case study 9, the harmonization of the technology mix data between the models needs to be planned carefully as the two models use different units to measure the consumption of such commodities. REMES EU has data defined in million Euros, while GENeSYS-Mod considers physical quantities. This means that, even considering the data related to the consumption of different energy commodities allocated in percentage over the total, the two models might deliver different results. As a mention we could have that REMES EU has an initial use of biofuels of 10% over the total consumption of energy in a particular sector in the base year, whilst GENeSYS-Mod has an initial percentage of 7% for the same sector and same year. If the future projected consumption of biofuel by GENeSYS-Mod is 9% it is plain wrong to use this percentage in REMES EU because, being the initial share of biofuels 10%, applying the output from GENeSYS-Mod as is would involve having a decrease in the use of biofuels in REMES EU, which would be in contradiction with the results from GENeSYS-Mod.
- In case study 3, it was not easy to link models featuring very different representations of hydraulic generation. It is necessary to agree on the level of detail to consider for these elements in the different models, i.e. which kind of simplifications to make in each one, in order to ensure :
  - Consistency across all the models
  - Representation of the reality in as much detail as possible
  - Availability of data to feed each of the models taking into account the agreed upon type of representation to be made of these assets.
- In case study 4, the plan4EU model used mostly outputs of the SCOPE model to build its input dataset. However, regarding the hydropower mix, some data were not available within SCOPE and the dataset had to be enriched from other sources, which proved somehow difficult given the differences in the level of disaggregation of hydropower generation between the two models. In particular it proved difficult to identify which part of the hydropower capacity can be seen as seasonal storage and which part can be seen as pumped storage. Also a difficulty arose with the representation of CHP (Combined Heat and Power), given that SCOPE is a multi-energy model and plan4EU is a purely electricity model. The non-flexible part of CHP, from the point of view of the electricity system needed to be identified, as well as the flexible part.

### Iterative process

In the implementation of the linking between the Top-Down and Bottom-Up models, the Top-Down model is treated as a nonlinear Mixed Complementarity Problem. A significant implication of this structure is that the model can choose whether to introduce or not new commodities, such as hydrogen, within the economy in a given year, based on their relative profitability. The decision of whether to introduce these commodities is contingent upon the evolution in their relative prices compared to the price of competing commodities and on the price of the inputs necessary to produce them.





In some iterations, hydrogen production could become necessary, albeit in small quantities, due to the evolving energy mix within particular (sometimes small) sectors. The introduction of hydrogen, which was absent in the previous iteration, results in a significant relative divergence in results from the new iteration when compared to the previous one. This causes the infinite norm on the difference in relative values of the results from the Top-Down model in two subsequent iterations, the measure used to test the convergence of the procedure, to be highly inflated. However, if hydrogen becomes a constant in the solution set, we observe that the infinite norm stabilizes due to the absence of variables switching from zero to positive. Nevertheless, it is often noted that hydrogen, which might in some iteration appear in the energy mix as defined by the Bottom-Up model, might disappear once the activity levels of the production sectors are relayed from the Top-Down model to the Bottom-Up model. This happens when the Top-Down model informs the Bottom-Up model that the sectors requiring hydrogen are not producing as much as they were assumed to produce in the previous iteration and the Bottom-Up model modifies the energy input of these sectors, which do not require to purchase hydrogen any longer.

The inconsistency in the presence of hydrogen – its intermittent appearance and disappearance – leads to an erratic behavior of the convergence measure, namely the infinite norm. This volatility vanishes if we substitute the infinite norm with the mean absolute deviation as a convergence measure. The mean absolute deviation does not consider the largest deviation in the solution vector between two subsequent iterations but rather computes the average positive deviation. This average smooths out discontinuities by blending them with changes from other variables that are more stable (or 'well-behaved'). These 'well-behaved' variables do not fluctuate between zero and positive values, contributing to a more stable convergence measure. Consequently, the use of the mean absolute deviation reduces the unpredictability in the convergence measure and enhances the robustness of the linking procedure.

### 3.6 Extension of the nomenclature

In many case studies, it turned out, during the process of conducting the case study analysis, that some definitions were missing in the nomenclature or were not fully adapted to the needs within the case study. A very clear, accurately defined, process needs to be implemented in order not to create misunderstandings, or useless or too-complex variable names, or delays due to the lack of some relevant variables within the nomenclature at the stage of uploading results.

It is advised to very accurately define the list of variables, regions (including interconnections of regions) and subannual time slices that will be needed by the case study early enough, so that those are included in the nomenclature and scenario explorer before the process of uploading data starts.

In the case of local studies (for example, in case study 6), the temporal scope considered adapts well to the nomenclature defined, but the spatial and temporal resolution of the variables in the nomenclature are not well adapted to the case study needs. Indeed, case study 6 focuses on a local energy system considering an hourly resolution of data. A potential future improvement of the nomenclature could be to disaggregate the countries into several bidding zones. This is already possible via an extension of the list of regions within the nomenclature, but has not been done during the project.



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