Definition of the interface between the models in the suite and the Common Database

DELIVERABLE NO. D5.2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 835896

Deliverable No.	**D5.2**	**Work Package No.**	**WP5**
Work Package Title	A suite of modelling tools		
Status	Final	(Draft/Draft Final/Final)	
Dissemination level	Public	(PU-Public, CO-Confidential)	
Due date deliverable	30.06.2020	Submission date	05.07.2020
Deliverable version	V4		

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History of Change

Release	Date	Reason for Change	Status
Draft	22.06.2020	V1: Achieved almost all content	Small loose ends remain
Apply review feedback	26.06.2020	V2: Major formatting update and apply review recommendations	Partial complete
	29.06.2020	V3: further quality check and figures inclusion from Case studies	Almost complete
Final version	05.07.2020	V4: Improvements to CS8 and throughout formatting check.	Deliverable Finalized

DISCLAIMER / ACKNOWLEDGMENT

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Table of Contents

1. Introduction

1.1 Background

The greenhouse gas emissions (GHG) reduction targets adopted by the European Commission will lead to the definition of a wide array of policies spanning over different aspects of the economic, technological, and societal system. The green transition will be carried out through the implementation a disruptive reconfiguration of each of these systems and will determine a profound impact on both production and consumption standards. The effects of each policy can be studied under different levels of granularity, but there is shared agreement that dedicated analyses carried out by experts from each of the potentially impacted fields will provide more depth to the insights and improve the overall quality of the results.

For many years, researchers from different fields have studied phenomena establishing clear boundaries on what is endogenous to their analyses and what is to be taken from external studies or databases. This approach, considering what is external to the model boundaries as a „*hic sunt leones*" territory, often led to the determination of biased results due to the lack of a reliable set of information or the inability to establish mutual feedback mechanisms between the endogenous and exogenous parts of the models. Albeit acceptable for policies that are only supposed to provide a marginal change to the considered system, the methodology does not fit a framework where large shocks will take place producing ripple effects over different interrelated fields.

In this respect, enabling data sharing between models in a consistent and standardized manner would provide mutual benefits to each research area. To this end, the ambition of the openENTRANCE project is to develop, use and disseminate an open, transparent, and integrated modelling platform for assessing low-carbon transition pathways of the European energy system. One of the cornerstones of this platform is to have an accessible database. An open common database would constitute a powerful tool, improving the modelling efforts under several dimensions:

- *It would make the analyses results more robust*: A formalized and automated exchange of data between the models would make the communications between modelling teams faster and less error-prone, therefore leading to an increase in speed for analysing case studies. In this regard, the openENTRANCE project will perform nine case studies[1] dealing with emerging challenges of the energy transition, for example, the role of different technologies to enhance the flexibility of the energy system, or the energy demand behaviour of communities.
- *It would make it easier to re-use models*: Both models and datasets interacting with the common database will be open. This, coupled with a standard methodology for the data exchange, will grant easy interaction with the suite of models by any interested researcher.

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[1] See an overview of case studes at https://openentrance.eu/case-studies/

- *The modelling process would be more transparent*: The common database will be complemented by visualization tools. These tools make the input and output data for energy system modelling easily available for anybody. This will make the modelling processes more transparent and more robust.

In openENTRANCE, the modelling platform will among other be populated with a suite of modelling tools and a database for sharing, storing, and making input and output data visible. The database called "openENTRANCE scenario explorer[2]" will enable transparent and open data exchange between the suit of models. The first datasets of four quantified pan-European scenario results are uploaded to the openENTRANCE scenario explorer for further use. These datasets have been defined by running an instance of the GENeSYS-MOD and build the empirical foundation of the entire openENTRANCE project. These datasets as well as further generated ones under the case studies and the macro-economic exercises are also fully open and available to the entire research community for further use to conduct own studies.

The data exchanged between the openENTRANCE scenario explorer and the modelling teams complies to a standardized format, initially developed by the Integrated Assessment Modelling Consortium (IAMC) and further expanded to facilitate the application to the use cases developed within the openENTRANCE project. This format has been first described in deliverable D4.1. The common data format is a standardized structure defined to exchange data between models and the openENTRANCE scenario explorer. Each entry of data files complying with this structure are composed of the following fields: model name and version, scenario name, region, variable name, sub-annual (time granularity) and (measure) unit. The variables considered by the data format are based on a glossary of common terminology that has been subject to incremental refinements during the past months of the project activity and are described in the project's GitHub repository[3]. Different modelling teams operating in different research areas have contributed to expanding the set of variables according to their typical needs. Variables are grouped into four macro-categories: economy, emissions, energy, and technology. The first group defines variables and indicators related to the economy and societal drivers such as population, the second group defines variables and indicators related to emissions, carbon sequestration and the impact of emissions on the climate, the third group defines variables and indicators related to characteristics and specifications of (energy) technologies including power plants, transmission lines and pipelines, while the fourth group includes three top-level indicators related to the energy supply chain (also called reference energy system), namely Primary Energy, Secondary Energy and Final Energy Within each group, variables are defined based on a "semi-hierarchical" structure that denotes the depth of description. As a

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[2] The openENTRANCE scenario explorer is a common database used in the project to open data from models and use it in case studies. This also has tools for visualisation, aggregation/disaggregation and others.

[3] https://github.com/openENTRANCE/nomenclature

mention we could have `Emissions|CO2`, which can be further partitioned into two variables, namely `Emissions|CO2|Energy` and `Emissions|CO2|Other`. The names used in the nomenclature are mandatory for any data reporting.

1.2 Deliverable objectives

The objective of Deliverable D5.2 is to provide a description of the interactions that shall be enabled between the models and the openENTRANCE scenario explorer. This will be done by introducing a formalized description of the interactions that the openENTRANCE partners will perform with their modelling tools around the database to implement a set of case studies. This will serve as the groundwork for the establishment a knowledge base about the usage of an European common platform for collaborative research. Moreover, the analyses introduced in the present deliverable constitute one of the first exercises to analyse EU carbon policies under a multifaceted framework, but for the first time and in a systematic manner, without the need of establishing a trade-off between the amount of dimensions considered and the level of detail in which each dimension is studied.

More in detail, deliverable D5.2 has two main objectives:

- Describe in a formalized way the interactions that each openENTRANCE case study team will have with the openENTRANCE scenario explorer. Each case study will be outlined in detail, complemented by the description of the models utilized to perform the analyses and the workflow necessary to establish a communication between the models using the database.
- Outline the methodology to interact with the openENTRANCE scenario explorer to upload, download and visualize data.

This will constitute a fundamental step to devise a methodology to link and combine several drivers responsible for possible future developments determining the features of an energy and transport system in the long-term and to better combine or link energy system models.

At the end of the document there will be a visual demonstration of the utilization of the openENTRANCE Scenario Explorer in form of screenshots from some of the considered case studies.

1.3 Structure of this report

To define the principles underpinning the communications flow of the different models and the openENTRANCE database and present the interactions within the case studies, this report is organised as follows:

- Chapter 2 provides a summary of the scenarios developed within the project and their quantification using GENeSYS-MOD. The interactions between the model and the openENTRANCE Scenario Explorer will be described in this chapter.

- Chapter 3 contains the description of all the case studies, the characterization of the models utilized in each of the cases as well as a formalized explanation of their communication workflow with the openENTRANCE scenario explorer.
- Chapter 4 outlines the next steps in the work packages and the openENTRANCE project.

The deliverable is complemented by two appendices:

- Appendix 1 contains the guidelines for the utilization of the openENTRANCE scenario explorer. Here one can find a detailed explanation on how to upload, download and visualize data.
- Appendix 2 presents a list of the variables exchanged between each case study and the openENTRANCE scenario explorer according to the nomenclature defined within the project.

2. openENTRANCE scenarios and GENeSYS-MOD inputs-outputs

The openENTRANCE project aims to provide policy insights into a set of possible futures of the European energy system.. Thus, a set of paradigmatic, possible, futures, defined along several crucial technical, economical, and social dimensions have been built for a start. This is reported in deliverable D7.1. These futures are called storylines, and have initially been defined qualitatively. However, modelling the functioning of the energy system in each of these futures, to draw conclusions on the optimal policy to implement in it, requires defining these futures quantitatively speaking, thus determining the scenarios to be considered in the analyses within the project.

The set of modelling tools considered within openENTRANCE are aimed at assessing a wide variety of complementary aspects of the operation and expansion of the energy system, as well as the impact of the energy system on the functioning of the whole economy. All these are explored in the analyses within Case Studies (CS), in WP6, as well as in Pathway analyses, in WP7, from a holistic point of view. The modelling analyses within WP6 and WP7 need to take place in a certain context, corresponding to the several scenarios defined in the project. For each scenario, the overall evolution of the energy system and the framework conditions to be taken as an input in CS and pathway analyses are computed, within WP3, making use of the GENeSYS-MOD model. This is reported in D3.1[4]. The several sections that comprise this chapter are briefly described next.

In section 2.1, we provide the high-level characterization made of the storylines considered in the openENTRANCE project.. As aforementioned, based on the storylines characterization, quantitative scenarios have been defined within the project. Afterwards, in section 2.2 and section 2.3, we describe the features, inputs and outputs, respectively, of the model GENeSYS-MOD , used to compute the general evolution of the European energy system and the framework conditions for each of the scenarios defined. Finally, within section 2.4, the main results computed for the several quantitative scenarios using the GENeSYS-MOD model are briefly discussed, as in D3.1.

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[4] https://openentrance.eu/wp-content/uploads/openENTRANCE-D3.1.pdf

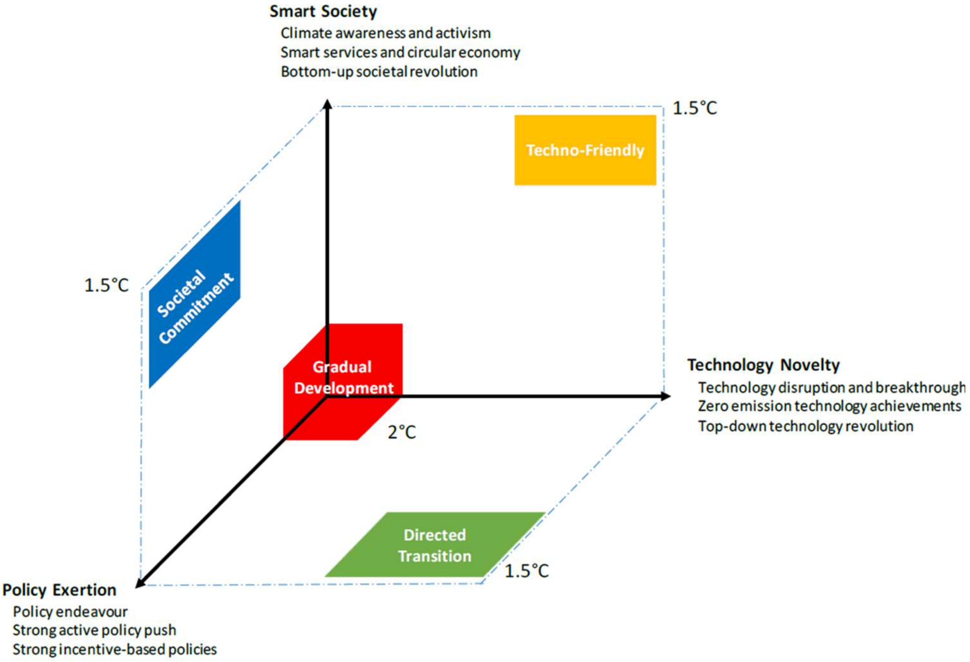

Figure 1: openENTRANCE storylines typology = policy exertion x technological novelty x smart society

2.1 openENTRANCE Storylines at a Glance

The three-dimensional topology depicted in Figure 1 has been used to set stories around key drivers and uncertainties of the energy transition. This topology indicates the place of three exposed future qualitative storylines (and thus quantitative pathways) on the extreme ends of a three-dimensional space as well as a more conservative future development in the centre[5].

Each exposed storyline is defined by the combination of two sets of (key) drivers. As depicted in Figure 1, we have then the four storylines:

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[5] It is important to note, that at a later stage of the openENTRANCE project a fifth pathway is briefly analysed in addition, containing several of the main features/ingredients of the three exposed pathways presented in this framework (see chapter 5 of this document). Contrary to the fourth pathway presented here (Gradual Development) containing 'a little of each' of the remaining three, the fifth pathway rather includes 'a lot of all'. At this stage, however, the focus is on the four pathways only, in order not to blur the contours of the drivers/features of the remaining individual openENTRANCE pathways.

- Directed Transition
- Techno-Friendly
- Societal Commitment
- Gradual Development

Overall, the drivers and uncertainties surrounding technology development, policymaking and societal engagement characterize the qualitative storylines. The dimensions in Figure 1 are conceptually shaped by considering the positive (quadrant) aspects on:

- “Smart society” dimension: Maximises the engagement and awareness of the society to take concrete actions to combat climate change. It is characterized by strong support from the public and active participation (climate activism) on changing attitudes and behaviour in lifestyles.
- “Policy exertion” dimension: Represents a world in which effective policy measures successfully steer the energy transition to decarbonisation. Institutions and regulations drive the energy transition (top-down decisions) based on cooperation, low-geopolitical tensions, centralized initiatives and a strong EU.
- “Technological novelty” dimension: Innovation and technological breakthroughs dominate the quadrants surrounding this axis. Rapid technological learning helps to bring various technological options to commerciality and hence have an active role in the energy transition.

Based on these definitions, the combination of the dimensions (shared quadrants) results into an interesting three storylines description and a middle way.

2.2 GENeSYS-MOD model: main features

The Global Energy System Model (GENeSYS-MOD) is a cost-optimizing linear program (LP) aimed at computing the development and operation of large-scale energy systems (although other applications are possible). It has a special focus on sector-coupling and interlinkages. GENeSYS-MOD is based on the Open Source Energy Modelling System (OSeMOSYS), an open-source model used to carry out long term energy system analyses. OSeMOSYS is being developed in a collaborative and decentralized manner by researchers worldwide. It has been used in a large number of published analyses both of a scientific and policy advisory type. The objective function of the model represents the total cost of providing energy to the electricity, transport, heating, and several industrial sectors within a region. The model, therefore, computes the least-costly combination of technologies to be used to meet energy demand. Climate targets, either as a CO2 emissions budget or in the form of sector specific CO2 prices, are provided as an input to the analysis conducted with this model. The CO2 budget, or CO2 price, is set to meet the climate change targets regarding the maximum warming to be allowed in the considered scenario. When considering a budget, this is commonly obtained from the global one by breaking it down into shares based on amount of population in each region.

Figure 2 below provides a general, simplified, representation of the structure of the model regarding the sectors, technologies and energy carriers considered within it, as well as the main interactions taking place among the former.

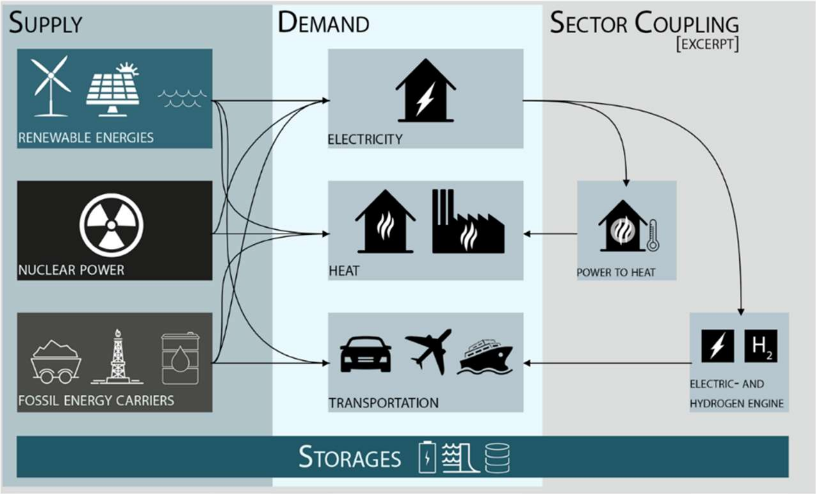


Figure 2 : General structure of the GENeSYS-MOD model

With respect to the original version of the model, existing prior to the openENTRANCE project, several upgrades have been made to the model. These are described next:

- A regional update has been conducted from initially 17 European countries/regions to 30 (i.e. Mainland-EU25, UK, Switzerland, Norway, Turkey, and the Balkan region).
- In terms of temporal resolution, the initial time slices were replaced by a reduced hourly resolution and a time-clustering algorithm. In order to compute scenarios results in the project, 24 time slices in total have been considered, corresponding to 4 representative days represented by 4-hours slices each. The reduced time series computed have been adapted to meet the maximum/minimum/average values of the total time series.
- A more disaggregated representation of the industry sector, in terms of the energy carriers and technologies used, has been implemented.
- As previously mentioned, the CO_2 budget functionality has been disabled and replaced by a CO_2 price mechanic.
- Scripts have been developed to convert scenario results to the openENTRANCE data format.

2.3. Mapping data inputs and outputs from GENeSYS-MOD

Within this section, the main inputs and outputs of the GENeSYS-MOD model are listed and briefly described.

A list of the main inputs follows:

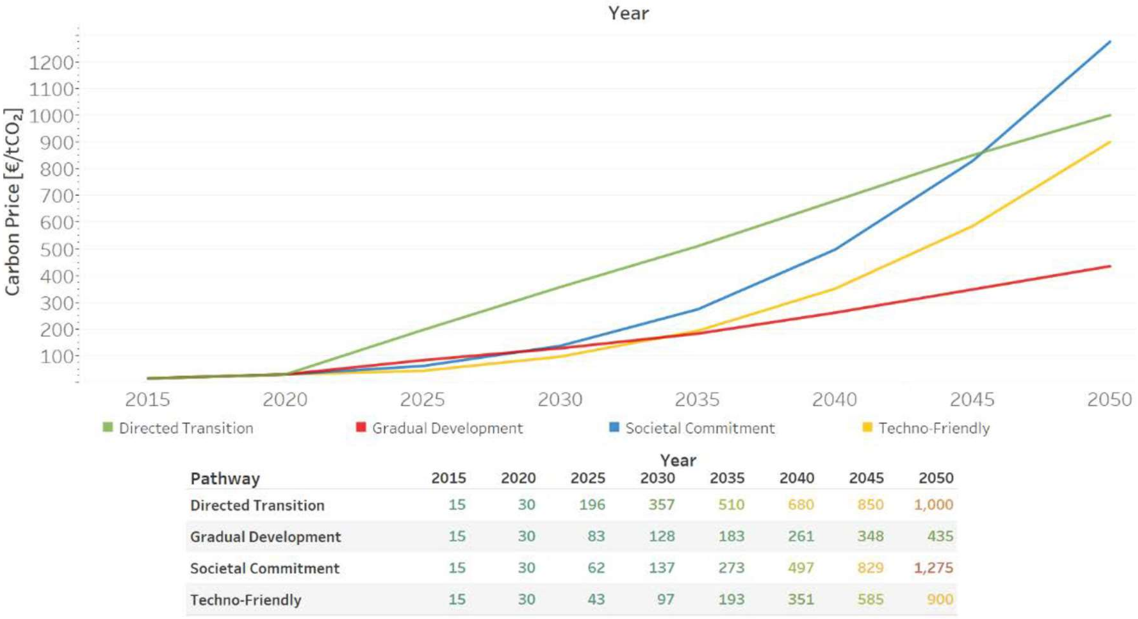
- Fossil fuel prices: essentially determine the economics of energy production/generation technologies as well as the trade-offs among competing (low/zero emission) technologies qualified to deliver the same energy services (like heating, cooling, mobility, and others).
- CO_2 prices and/or CO_2 budgets: Both of these two CO_2-emission mitigation instruments can be used in modelling to govern exogenously the decarbonization pathways. In modelling, CO_2 prices usually add to the cost of an emitting production/generation technology or result in a surcharge in the prices of the energy services in the retail sector.
- Technology cost/learning rates: the assumptions made on the technology costs and the expected technological learning rate in the future are determining parameters defining the timing of the market penetration of future technologies/technology portfolios and, thus, the decarbonization pathways.
- Renewable resource potentials: In an almost 100% renewable European energy system in the long-term, it is relevant to consider robust estimates of the renewable resource potentials in the different European regions and countries.
- Energy demand projections: Last but not least, empirical datasets on energy demand projections in the different sectors, and energy end-uses, are also being input into the model.

As for the main outputs, they are listed and described next:

- Evolution of the primary energy use, per energy carrier and area considered in the system, until 2050.
- Evolution of CO2 emissions per area and sector (Building, Industry, Power, Transportation, and Carbon Dioxide Removal) until 2050.
- Evolution of electricity generation (energy and capacity) per technology and area until 2050.
- Evolution of high temperature heat generation per sector, technology, and area until 2050.
- Evolution of passenger mobility and freight transportation per technology until 2050.

2.4 Short overview of GENeSYS-MOD results on openENTRANCE scenarios

When assessing the results computed on the general evolution of the system in the scenarios considered, one must bear in mind that these scenarios significantly differ in the implemented carbon prices and their respective developments. For Gradual Development, Societal Commitment, and Techno-Friendly, an exponential development of carbon prices, considering an initial low value of these, and high levels in the last periods, is implemented. For Directed Transition, on the other hand, a linear growth of the carbon price is assumed. Then, carbon prices in the latter, between 2025 and 2040, are substantially higher than in the rest of the scenarios, due to the strong policy measures put in place. In 2050, Societal Commitment requires the highest carbon price to reach its 1.5°C compatible pathway goal, which amounts to 1275€/tCO_2. This is mostly due to the absence of carbon dioxide removal technologies. The second highest carbon price in 2050 corresponds to the Directed Transition scenario. This amounts to 1000€/tCO$_2$, see Figure 3.



	Year							
Pathway	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Directed Transition	15	30	196	357	510	680	850	1,000
Gradual Development	15	30	83	128	183	261	348	435
Societal Commitment	15	30	62	137	273	497	829	1,275
Techno-Friendly	15	30	43	97	193	351	585	900

Figure 3: carbon price evolution for each of the scenarios

A decrease in primary energy use can be observed in all the scenarios. However, in 2050, the primary energy demand varies by as much as 10 EJ across the scenarios. Within Societal Commitment, with its focus on societal change, meaningful demand reductions take place due to a change in the lifestyle, as well as demand patterns. Gradual Development corresponds to the other end of the spectrum, being the least ambitious scenario in terms of climate change targets (featuring a 2°C compatible target).

As for the installed electricity generation capacities, results for the scenarios are broadly similar as far as the major dominating renewable technologies are concerned. The driving forces behind the deployment of these are, however, significantly different in the different scenarios. There is, in any scenario, a slight increase of hydro-power generation and a significant increase of wind (onshore and offshore), as well as PV generation, up to 2050. However, the shares of onshore and offshore wind as well as PV differ significantly across scenarios. Thus, for example, in the Techno-friendly scenario, offshore wind and onshore wind are equally abundant. In addition, also the speed of the capacity deployment varies across scenarios. In Directed Transition there is a strong early increase in installed capacities, which stay nearly constant from 2040 onward. On the other hand, in Gradual Development fewer capacity additions in the first periods take place. However, in 2050, the overall renewable generation capacity in this scenario is the largest one. This is due to the absence of carbon dioxide removal technologies, as well as a lack of strong demand-side reductions compared to other scenarios. Lastly, in Techno-Friendly, the installed electricity renewable generation and storage capacities are smallest, since, in this scenario, hydrogen has a large relevance. Regarding the storage capacities, all the scenarios feature the same overall capacity development. In Directed Transition, storage capacities are installed the earliest, but these are topped in 2045 and 2050 by those in Gradual Development and Societal Commitment. The observed patterns of the installed electricity generation capacities are also visible when looking at the evolution, year by year, of the power generation per technology.

Regarding the role of the hydrogen in the future European energy system, significant differences across the scenarios can be observed. The politically enforced early transformation of the energy system in the Directed Transition scenario results in a large use of hydrogen in this scenario. Besides, whereas in Societal Commitment and Techno-Friendly the hydrogen usage increases significantly between 2035 and 2040 and reaches a high share in 2050, in Gradual Development hydrogen starts to be used significantly towards 2050, only.

In addition, the level of further electrification of the energy system is relevant, within several sectors, in all the scenarios. In the residential and commercial sector, it concerns switching to heat pumps. In the industry sector, there is an increasing electrification of the production of process heat. In the transport sector, there are numerous relevant transformations contributing to this, from BEV adoption to the deployment of the electric rail, and the overhead trucks. Within Techno-friendly, the electrification of the industrial and transport sectors is the least relevant, due to the use of carbon dioxide removal technologies.

The CO_2 emission evolution is very similar in Techno-Friendly and Societal Commitment. In both, the emissions are almost null from 2040 onwards. In Techno-Friendly, negative emissions take place in the energy sector in 2045 and 2050. In Directed Transition, CO_2 emissions decrease substantially very early. Then, the emissions between 2025 and 2040 are smallest in this scenario. On the other hand, emissions in Gradual Development are highest from 2025 onwards. Still, net emissions in this scenario are almost zero in 2050.

The availability of carbon dioxide removal technologies significantly affects the scenario results when a limit of the global temperature increase of 1.5°C is enforced. The two scenarios where carbon dioxide removal technologies are not available feature the largest net increase in electricity generation and capacities. This is partly due to the use of large amounts of electricity in the electrolysis to produce renewable hydrogen.
The results computed and provided here show that a strong enforcement of the climate objectives by the policy authorities can significantly accelerate the pace of decarbonization of the energy sector. What is more, there is the risk that the required transition does not materialize fully in time if the required change in the public attitude and the critical technology breakthroughs do not happen.

Some key insights resulting from the scenario analysis with GENeSYS-MOD, to be corroborated afterwards in the case study and further pathway analyses, are listed next:

- If we are going to limit the global temperature increase to 1.5 °C, significant efforts need to start now
- Already in 2030, the emissions in Europe must be around 1/3 of today's level only
- This underlines the importance of the policy measures aimed at facilitating the future energy transition when a less risky strategy is implemented (as in Directed Transition)
- A novel technology breakthrough (as in Techno-friendly) or a fundamental society's lifestyle change (as in Societal Commitment) can also allow us to meet the existing ambitious climate-related goals. However, there is a high risk that the corresponding novelties and adaption processes do not take place in the next decades until 2050
- Half or more of the residential and commercial heating needs to be provided by heat pumps already in 2035, unless carbon dioxide removal technologies are available
- Half or more of passenger transport needs to take pace using BEV already in 2030
- Avoiding the last 1/3 of the emissions taking place in 2030, by 2050, requires that CO2 prices increase several times over and remain at high levels until 2050

3. Case studies detail workflow

The openENTRANCE project has a strong commitment into transparency and openness in energy system modelling. In this regard, the project has nine case studies that will serve to lead the way and show how this cooperative format can be implemented using a modelling platform developed within the project. Moreover, the case studies address key topical challenges relevant in the energy transition. In the following sections there is an introduction of each of the case studies identified within the scope of the project. Each case study will be briefly described, placing the focus on the objectives, challenges and expected results. This will be followed by a description of the methodology used to evaluate the case study, the involved models, and their characteristics, as well as the list of variables (see examples in appendix) that such models will exchange. Finally, there will be a detailed description of the planned workflow and the single interactions between the models will be depicted in appropriate process diagrams. A dedicated appendix illustrates the envisaged variables exchanges for each model involved in the case study and the openENTRANCE Scenario Explorer platform.

To understand the description of each case study and each sub-sub-section content, the following table provides an overview on how this report has designed the structure of the sub-sections and the objectives of their content.

Sub-Section	Description
1 Case study objective and challenges	This section introduces the objective of analysis of the case study. A list of research questions is introduced and discussed, considering the possible modelling novelties.
2 Detailed methodology of the case study: modus operandi	This section outlines the interactions between the openENTRANCE database and the models involved in the analysis of the case study. This section provides information about the role of each model in the collaborative setting.
3 Expected results and limitations	Here there is a brief summary of what the modellers expect out of each analysis as well as providing a delimitation of the boundaries of the modelling exercise.
4 Set of models	The core of this section is to introduce the details about the models used in the case studies. The scope of application of each model is described in the first part and then the details about the input-output data are included.
5 Workflow of the case study	In this section there are the details about the input-output interfaces between the involved models. This section features diagrams that explain the flow of communications between the involved models
6 General list of data	This section describes the data required by the models from either the openENTRANCE scenario explorer, a concurrent model or the database owned by the modelling team itself. This information is provided by the openENTRANCE database using a common data format (Format D4.1). The data format is generic and suitable to be used for a wide range of applications, including energy-systems analysis or modelling of specific sectors like transport, industry or the building stock.
7 Data workflow	This section contains the details of what was presented in 5. Namely, the workflow is formalized by means of process diagrams and the source, destination and content of each exchanged pack is described here.
8 Data exchange tools	This small section contains a description of the translation tools needed to ensure a seamless communication between the models and the openENTRANCE scenario explorer.
9 Execution order	This section explains textually the process defined in sub section 8.
10 Implementation in the openENTRANCE scenario Explorer	This section contains screenshots displaying the data loaded in the openENTRANCE scenario explorer by each of the modelling teams.
Appendix: exhaustive variable list	This annex contains a table with the name of each variable exchanged within the case study following the openENTRANCE data nomenclature.

The case studies introduced in what follows use as starting points the initial drafts introduced in deliverable 6.1 and elaborate further on the details related to the interplay between the models and the openENTRANCE database. More specifically, the subsections related to the overall objective and challenges, the detailed methodology of the case study (modus operandi), the expected results and limitations and, partially, the general list of data can be also found in deliverable 6.1. In this deliverable, these sections are expanded and/or integrated with additional information about the workflow and interactions between the models, and the openENTRANCE database.

3.1 Case Study 1: Demand response – behaviour of individuals

3.1.1 Case study objective, challenges and beyond the state of the art

This case study focuses on different modelling paradigms for residential electricity demand in both the short (hourly) and long (annual) term within the electricity system. The objective is to analyse the potential of consumers to shift electricity demand under different measures for flexibility. Data from real-life field-tests, recently carried out in several EU nations, will be used. Such data directly reflect human behaviour and individual choices related to electricity consumption and will contribute to an improved understanding of the potentials of demand response for the system and for individuals. The improved understanding of flexibility potentials will be input into the EMPIRE and plan4EU energy system models to assess the system level impacts of flexibility under various scenarios and regimes. The models will be used in parallel as they focus their analyses on different sectors of the electricity system, with EMPIRE focused on transmission and plan4EU focused on flexibility and renewables. Comparing the outputs of the two models across various scenarios and assumptions of demand flexibility will allow for a more holistic understanding of how demand flexibility can be considered in energy system models, and the consequences of this consideration.

Through this case study, national and European policy makers will be provided with significantly improved insights on demand response measures that support the effective and efficient integration of variable renewable electricity generation into the European grids and markets.

The baseline for this case study is the existing modelling frameworks of the EMPIRE and plan4EU models. Prior research also forms the baseline, firstly including Gils (2014)[6] who has estimated *theoretical* demand response potential for all European countries, differentiated by sector – which includes a "residential" sector. The study and EMPIRE module developed in Maranon-Ledesma and Tomasgard (2019)[7] is the baseline demand response module, using the quantities estimated in Gils (2014)[8], that will be updated in this Case Study. Finally, as a baseline guidance for how to input

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[6] Gils, Hans (2014). Assessment of the theoretical demand response potential in Europe. *Energy 67,* pp. 1-18.

[7] Maranon-Ledesma, Hector and Asgeir Tomasgard (2019). Analyzing demand response in a dynamic capacity model for the European power market. *Energies 12*.

[8] Gils, Hans (2014). Assessment of the theoretical demand response potential in Europe. *Energy 67,* pp. 1-18.

empirical, social science estimates of human behaviour into energy system models, we refer to past work in McKenna et al. (2019; 2020)[9].

The central challenges of CS1 are:

i. Generating empirically-validated representations of demand response that are consistent with behavioural data and theory regarding residential load-shifting.
ii. Adapting energy system models to the improved representation of demand response.

The beyond state-of-the-art elements of CS1 are:

i. Using empirically-informed demand response potential consistent with behavioural realities instead of purely theoretical ones.
ii. Coupling of large-scale pan-european quantitative micro-datasets (ECHOES survey and PEAKapp field test data) with large scale energy system models.

3.1.2 Detailed methodology of the case study: modus operandi

The plan4EU model will be used to simulate the short-term (hourly) integrated operation of all flexible assets and potentials of the pan-European electricity system with a regional geographical granularity, thus allowing the capture of cross-effects of different flexibility inputs. Plan4EU provides a modelling of household demand-response, including load shifting and load curtailment, taking into account accurate dynamics and constraints (e.g. the time-scale within the day for load shifting). However, up until now there has not been realistic, empirically-based, measures of household demand response potentials across EU countries. EI-JKU will provide estimates of demand response potentials at the country level, using the Gils (2014)[10] theoretical potentials as a starting point and scaling these potentials down based on the observed demand response program participation in the PEAKapp data and the stated willingness for automated demand response. This represents a theoretical shift in the methodology - where previous studies looking into demand flexibility look at the technical side, including the appliances owned by households in the nation and the residential load profile – CS1 includes then the behavioural side of demand response. This includes the willingness and ability to participate in behavioural demand response programs, and estimates of

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[9] McKenna, Russell, Diana Hernando, Till ben Brahim, Simon Bolwig, and Jed Cohen (2019). Deliverable 5.2 - Analyzing the impact of dynamic electricity prices on the Austrian energy system. PEAKapp Horizon 2020 Project Deliverable 5.2. http://www.peakapp.eu/publications/

McKenna, Russell, Diana Hernando, Till ben Brahim, Simon Bolwig, Jed Cohen and Johannes Reichl (2020). Analyzing the energy system impacts of price-induced demand-side-flexibility with empirical data. *Zenodo Preprint*. https://zenodo.org/record/3674642#.Xk0BfntCeUk

[10] Gils, Hans (2014). Assessment of the theoretical demand response potential in Europe. *Energy 67,* pp. 1-18.

the payments that are required to 'buy' units of demand response through household participation. The methods for estimating participation rates follow those laid out in McKenna et al. (2019; 2020)[11], and are described as econometric panel data models. The precise quantities estimated will be chosen based on the quantities represented in the plan4EU and EMPIRE models and will include those listed under the input data requirements in the preceding section. This analysis will incorporate a new addition to grid flexibility modelling: the risk (variance) of demand response flexibility estimates for each country. As econometric models can take account of the variance in estimated quantities and plan4EU has a module for stochastic quantities as inputs.

Demand response and load shifting potentials will be produced at the national level for scenarios chosen in concert with openENTRANCE scenarios.

Plan4EU simulations will be run with the new estimates of demand response included (volumes of potential load curtailment and load shifting with dynamic characteristics and variability, for each nation). The output will describe the value of demand response to the European grid. EI-JKU will then calculate the expected cost, in terms of discounted electricity prices, for the level of demand response employed by the model. This will allow for a never-before-possible comparison of the value of certain levels of demand response to their costs.

As demand response will influence the evolution of the electricity system in the long-term, the case study will also include an assessment on the role of demand response in future capacity-expansion-investment decisions and in supporting renewable balancing. For this purpose, the EMPIRE model will be used. It includes a modelling of Demand-Response expansion (strategic decision variables with investment costs) for different kinds of demand responsive loads. EI-JKU inputs will expand the capabilities of EMPIRE to estimate different amounts of demand response flexibility potentials and allow the model to reflect behavioural realities more accurately in the household sector.

Finally, comparisons on different scenarios will be performed, including simulations with plan4EU based on results from EMPIRE, both based on the new demand-response inputs and in accordance with openENTRANCE scenario input data and guidelines.

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[11] McKenna, Russell, Diana Hernando, Till ben Brahim, Simon Bolwig, and Jed Cohen (2019). Deliverable 5.2 - Analyzing the impact of dynamic electricity prices on the Austrian energy system. PEAKapp Horizon 2020 Project Deliverable 5.2. http://www.peakapp.eu/publications/

McKenna, Russell, Diana Hernando, Till ben Brahim, Simon Bolwig, Jed Cohen and Johannes Reichl (2020). Analyzing the energy system impacts of price-induced demand-side-flexibility with empirical data. *Zenodo Preprint*. https://zenodo.org/record/3674642#.Xk0BfntCeUk

3.1.3 Expected results and limitations

The focus of this case study is to gain new insights into:

- What is the potential of demand response, including sector integration;
- What are the needed policies and incentive systems to unleash the flexibility potentials in electricity consumption in the most effective and beneficial way;
- What are the long-term system effects of demand response in the transformation of the electricity system.

A key limitation is that CS1 is only considering the demand response potential in the residential electricity sector

3.1.4 Set of models

Table 1. Models used in CS 1

Models	Lead Partner	Main Objective
Micro econometric (ECHOES/ PEAKapp) models	EI-JKU	Produce parameters for practical demand flexibility potentials within given time periods and associated costs to use this flexibility in the energy system
plan4EU	EDF	Estimate the value of demand flexibility in future scenarios of the European electricity grid
EMPIRE	NTNU	Estimate the value of demand flexibility in future scenarios of the European electricity grid

Table 2. Summary of models requirements for CS 1

Model	Geography		Time		Technological scope
	Horizon	Granularity	Horizon	Granularity	
Micro econometric (ECHOES/ PEAKapp)	EU 27 + GB, TR, CH, NO	Household level	1 year, 2018, projected to 2030 and 2050	Various, as needed	-Behavioural demand flexibility -Centrally-planed demand flexibility (allowing utility company to manipulate power within the household)
plan4EU	EU27 (excl. Malta & Cyprus) + AL + BA + CH + ME + MK + NO + RS + UK	Regional: France and Germany: ehighway2050 clusters (defined in Nomenclature) Aggregated regions: Scandinavia, Balkans, Baltics The rest: countries	1 year (2050)	Hourly	-Electricity transmission -Electricity generation, storage and uses (with focus on flexibilities) , from the above scope

EMPIRE	EU 27 (less CY and Montenegro), + GB N. Macedonia, Serbia, CH, NO	Country level, considering 55 interconnections	Every 5th year up to 2050	Representative weeks for each season (summer, winter, spring, and fall) depicted at hourly resolution	• Electricity transmission • Electricity generation and storage

Micro-econometric (ECHOES/PEAKapp)

CS1 will make use of available micro-level data relating to consumer energy choices (ECHOES), and field test data from a demand response field trial with residential households (PEAKapp). These data will be combined, using the methods developed in Gils (2014), to calculate demand response potentials for residential households related to 10 specific household technologies (Refrigeration, Washing Machine, Dryer, Dish Washer, Air Conditioning, Water Heater, Space Heater, Heat Pump, Electric Vehicle, Cooking). The baseline calculation is based on the number of households in each NUTS 2 region, and the ownership rates for each technology, e.g. the percentage of households owning a given technology. This yields a technical limit for the available load that can be shifted from each technology. PEAKapp and ECHOES data will be used to tune this technical limit based on the observed participation and state willingness to participate in demand response from the micro-level data. This model will be implemented in Python and made open-source according to FAIR principles. The ambition is to make the assumptions within the generation of demand response potentials clearly explained and marked, and quantitatively documented. Thus, using the open source script, other researchers can change assumptions and examine the effects on estimated demand response potentials. An early version of this system is viewable at github[12].

Plan4EU modelling framework

CS1 will make use of the scenario valuation layer of plan4EU. The Scenario valuation layer evaluates the investment decisions from the capacity expansion model by means of modelling the operation of the existing assets in the energy system. This layer contains two distinct models, the first model is referred to as the seasonal storage valuation (SSV) model and the second model is referred to as the European unit commitment (EUC) model. Those 2 models are 'hard-linked', meaning that the EUC is used as the solver for evaluating sub-problems created within the SSV.

Seasonal storage valuation model (SSV)

The objective of the seasonal storage valuation model is to provide an accurate account of "the value" that seasonal storage can bring to the system. Indeed, such seasonal storage (e.g., cascaded reservoir systems) can be used to store energy over large spans of time and use this "stored" energy when most needed. The actual use may in particular depend on adverse climatic situations (intense cold), but the ability to store the energy may in turn also depends on climatic conditions (e.g. draught). It is

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[12] https://gist.github.com/omnipotent12/040b8c5a5f290b574271ab01d6a92923

therefore clear that such a vision of value should be transferred in an appropriate way to shorter time span tools, such as the EUC model. In turn computing an accurate value intrinsically depends on the value of substitution, and thus ultimately on the EUC tool as well.

European Unit Commitment (EUC)

The EUC model computes an optimal (or near optimal) schedule for all the system assets on a typical period of one year, with a typical granularity of one hour in order to satisfy demand and ancillary services at the lowest cost. It ensures that the given system is « feasible » in the sense that at each hour of the year, including peak hours, it is able to fulfil the following constraints

- power demand supply;
- ancillary services supply;
- minimal inertia in the system;
- maximum transmission and distribution capacities between clusters;
- technical constraints of all assets.

EMPIRE model

The EMPIRE model provides decarbonization strategies and changes over time on the overall technology mix in the power system. That is, EMPIRE estimates the necessary technology and their operations to accomplish a given CO2 target. It determines endogenous investment decisions on generation and transmission expansion. It also provides hourly profiles on supply-demand operations per country. CS1 will consider the analysis of the economic impacts of different policies to foster the integration of Renewable Energy Sources, including the role of residential demand side flexibility.

Input data

Granularity and temporal scale of the data is determined by the model scope as defined in the table above. As this is an exploratory case study of the way and potential for residential demand flexibility to be incorporated into these models, specific parameters of the input/output data are tentative at this stage.

Plan4EU:

- Electricity demand projections 2050 for all EU countries, separated into uses (heating, cooling, transport, other)
- Energy technology parameters
- Technologies efficiency, ramping constraints and conversion
- Generation profiles
- Renewables potentials and profiles
- Demand flexibility potentials for each day of a representative year.

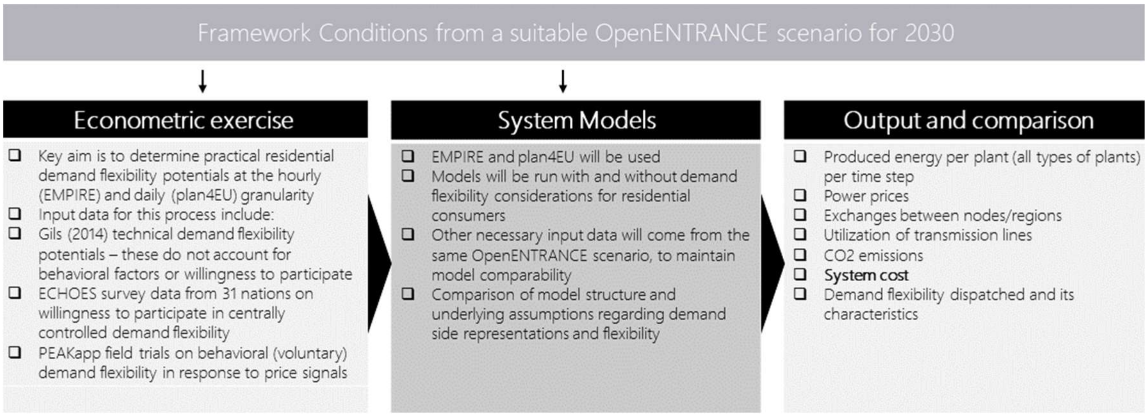
EMPIRE:

- Electricity demand projections 2020-2050 for all EU countries
- Energy technology CAPEX and OPEX
- Technologies efficiency, up-ramping constraints, and conversion
- Grid transmission expansion: investment costs and candidate lines considered
- Renewables potentials and profiles
- Demand flexibility potentials in four time series of 168 hours (for regular seasons) and two time series of 24 hours (for peak seasons).

Output data

Both the plan4EU and EMPIRE models will output critical policy and planning related parameters of interest, such as:

- Optimal electricity mix
- Transmission and capacity investments
- Demand flexibility dispatched and related schedules
- System cost parameters (variable costs, marginal costs, total system costs)
- System revenues (generation revenues)



Framework Conditions from a suitable OpenENTRANCE scenario for 2030

Econometric exercise

☐ Key aim is to determine practical residential demand flexibility potentials at the hourly (EMPIRE) and daily (plan4EU) granularity
☐ Input data for this process include:
☐ Gils (2014) technical demand flexibility potentials – these do not account for behavioral factors or willingness to participate
☐ ECHOES survey data from 31 nations on willingness to participate in centrally controlled demand flexibility
☐ PEAKapp field trials on behavioral (voluntary) demand flexibility in response to price signals

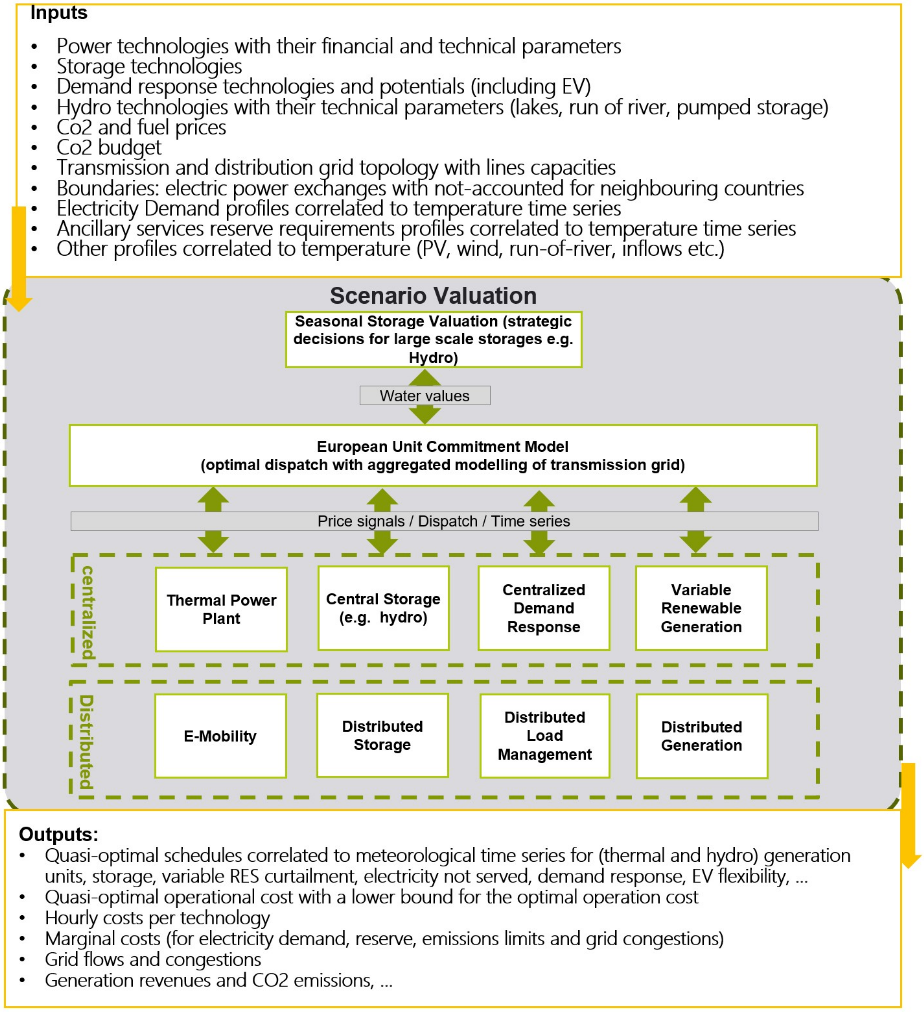
System Models

☐ EMPIRE and plan4EU will be used
☐ Models will be run with and without demand flexibility considerations for residential consumers
☐ Other necessary input data will come from the same OpenENTRANCE scenario, to maintain model comparability
☐ Comparison of model structure and underlying assumptions regarding demand side representations and flexibility

Output and comparison

☐ Produced energy per plant (all types of plants) per time step
☐ Power prices
☐ Exchanges between nodes/regions
☐ Utilization of transmission lines
☐ CO2 emissions
☐ **System cost**
☐ Demand flexibility dispatched and its characteristics

Figure 4: Schematic overview of aims and outputs of CS1



Inputs

- Power technologies with their financial and technical parameters
- Storage technologies
- Demand response technologies and potentials (including EV)
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Co2 and fuel prices
- Co2 budget
- Transmission and distribution grid topology with lines capacities
- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Electricity Demand profiles correlated to temperature time series
- Ancillary services reserve requirements profiles correlated to temperature time series
- Other profiles correlated to temperature (PV, wind, run-of-river, inflows etc.)

Outputs:

- Quasi-optimal schedules correlated to meteorological time series for (thermal and hydro) generation units, storage, variable RES curtailment, electricity not served, demand response, EV flexibility, …
- Quasi-optimal operational cost with a lower bound for the optimal operation cost
- Hourly costs per technology
- Marginal costs (for electricity demand, reserve, emissions limits and grid congestions)
- Grid flows and congestions
- Generation revenues and CO2 emissions, …

Figure 5: Schematic overview of the plan4EU model

3.1.5 Workflow of the case study

One openENTRANCE scenario will be chosen as an overarching framework for this case study. An end year will also be chosen, possibly 2030, 2050, or both. The scenario will offer the necessary macro input parameters (estimated from the Micro econometric models) for the two system level models (e.g. price, demand, etc.). The narrative part of the scenario will be used to address any assumptions on demand side flexibility, for instance the uptake of electric vehicles. The demand side flexibility narrative in this case study will thus be embedded and harmonized with the scenario narrative. The figure below shows a general representation of the first iteration of this workflow. Essentially econometric inputs regarding demand side flexibility potentials will be input into the two system level models and the outputs will be compared under the same scenario and timeframe. The aim is to understand how demand side flexibility impacts the energy system.

We will endeavour to undergo this workflow cycle several times to assess the impact of demand flexibility on the electricity system under various scenarios and assumptions.

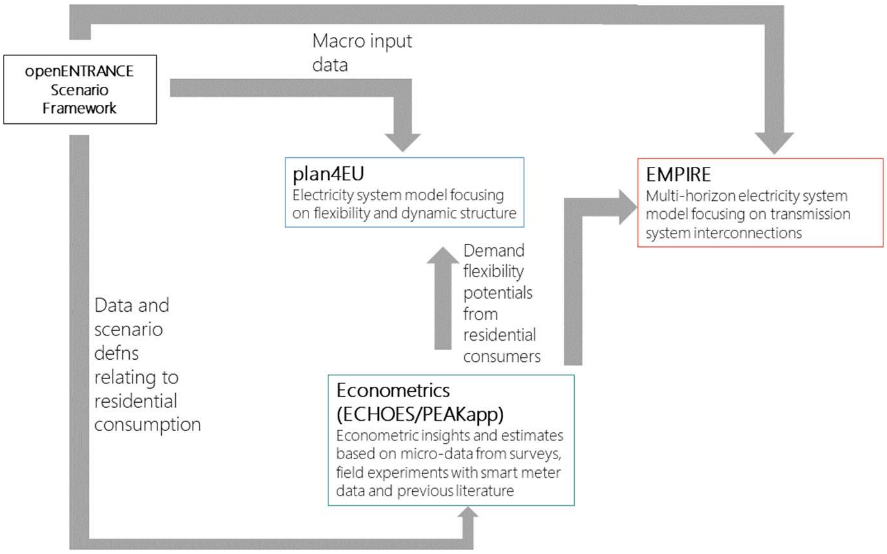


Figure 6 : CS1 general Workflow

3.1.6 General list of data

The following data lists illustrate key data sets needed to analyse the case study and its source.

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Energy demand per country per use in 2050
- Net electricity production from all sources of solar energy (e.g., solar PV and concentrating solar power)
- Investments into electricity generation and supply (including electricity storage and transmission & distribution)
- Fuel prices and CO2 emission price (or budget)

Data coming from modelling teams' own databases

- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Generation profiles for wind, PV, hydro correlated to meteorological time series
- Other generation profiles (biomass for example)
- Electricity Demand profiles correlated to temperature time series (including electric vehicle profile)
- Power technologies with their financial and technical parameters

- Storage technologies
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Demand response technologies and potentials.

Data produced during the case study exercise (mainly outputs of models)

- Transmission grid (capacities between nodes)
- Reference load profile at each node, corresponding to the standard aggregated consumption of electric vehicles connected to that node with a time step of one hour for some typical days (e.g. working day or weekend in spring/summer/winter).
- Flexibility is specified by an upper and lower deviation allowed around the reference load profile that should also be specified with a time step of one hour for some typical days (e.g. working day or weekend in spring/summer/winter).
- Practical residential demand flexibility potentials, at hourly resolution
- Installed capacities per country per technology in 2050

3.1.7 Data workflow

To illustrate the details of the workflow in a general and specific way, we refer to the example in Figure 7. Facts that are illustrated in the figure:

- The openENTRANCE database provides scenario information.
- There are three models that receive information from the database and outside the database
- There are tools to convert the data format that comes from each model to Common Data Format of the database and vice versa.
- Dashed lines represent the flow of information

It is considered 3 types of dataPacks:

- Whose content comes from openENTRANCE scenarios (**Pack1**)
- Whose content comes from model's own database
- Whose content comes from models' output (**Pack2**, **Pack3**, **Pack4** and **Pack5**) and is used as input for other models

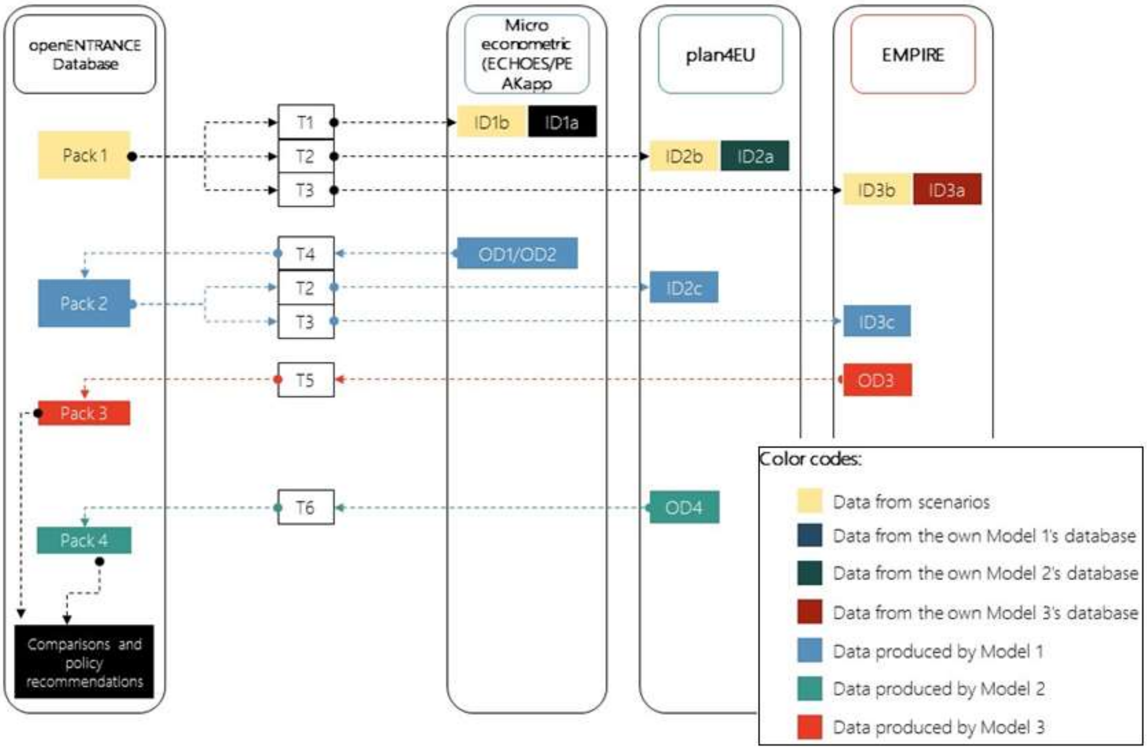


Figure 7 : Data workflow and examples

dataPack	Data flow	Content, as example:
Pack 1	Input data from Scenarios, common between models	Technology operation costs Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data exchanged between Model 1, Model 2 and Model 3 (from Model 1 Output to Model 2 and Model 3 input)	Residential demand flexibility potentials, and related cost parameters
Pack 3	Data outputs from Model 3	Output and comparison data, see Figure 4
Pack 4	Data outputs from Model 2	Output and comparison data, see Figure 4

List of Datasets (using the models' own formats):

ID1a	Input dataset **"part a"** that comes from the own **Model 1**'s database, *i.e. Reservoir topology*

ID1b	Input dataset **"part b"** that comes from the openENTRANCE database to **Model 1**, *i.e. energy resources, etc.*
ID2a	Input dataset **"part a"** that comes from the own **Model 2**'s database, *i.e. Investment costs, network topology*
ID2b	Input dataset **"part b"** that comes from the openENTRANCE database to **Model 2**, *i.e. Demand, etc.*
ID3a	Input dataset **"part a"** that comes from the own **Model 3**'s database, *i.e. Battery storage capacities*
ID3b	Input dataset **"part a"** that comes from the openENTRANCE database to **Model 3**, *i.e. Demand, capacities, etc.*
OD1	Output dataset from **Model 1** to openENTRANCE database, *i.e. demand flexibility potential in plan4EU specification*
OD2	Output dataset from **Model 1** to openENTRANCE database, *i.e. demand flexibility potential in EMPIRE specification*
ID2c	Input dataset **"part c"** that comes from the openENTRANCE database to **Model 2**, *Pass through of OD1*
ID3c	Input dataset **"part c"** that comes from the openENTRANCE database to **Model 3**, *Pass through of OD2*
OD3	Output dataset from **Model 3** to openENTRANCE database, *i.e. system cost parameters (euro per kWh supplied)*
OD4	Output dataset from **Model 2** to openENTRANCE database, *i.e. Transmission network expansion*

3.1.8 Data-exchange tools

The data exchange tools shown in Figure 7 are defined below:

T1 (OE-Model 1)	Set of tools or methods to convert data from the **Common data format** to **Model 1 format**
T2 (OE-Model 2)	Set of tools or methods to convert data from the **Common data format** to **Model 2 format**
T3 (OE-Model 3)	Set of tools or methods to convert data from the **Common data format** to **Model 3 format**
T4 (Model 1-OE)	Set of tools or methods to convert data from **Model 1 output format** to **Common data format**
T5 (Model 3-OE)	Set of tools or methods to convert data from **Model 3 output format** to **Common data format**
T6 (Model 2-OE)	Set of tools or methods to convert data from **Model 2 output format** to **Common data format**

3.1.9 Execution order

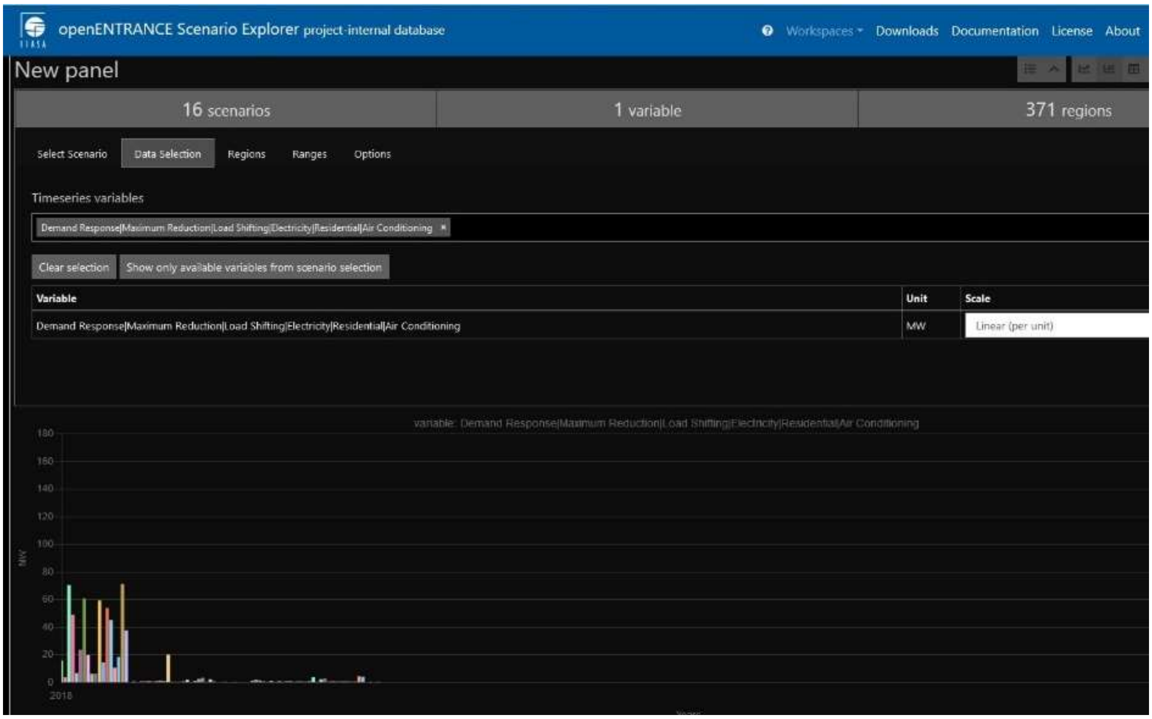
This section provides the stepwise plan to carry out the case study, specifying the data exchanged (with the relevant data-exchange tools if appropriate). An example is provided below:

Extraction of data from openENTRANCE Database: **Pack1** is structured according to the common nomenclature. It is transformed through **T1**, **T2** and **T3** into **Model 1**, **Model 2** and **Model 3** data formats **ID1b**, **ID2b** and **ID3b**.

1. **Building Model 1 Input dataset and running Model 1:** The Model 1's dataset is built out of Model 1 own data (**ID1a**) freely available from the web, from Gils (2014) and from the PEAKapp and ECHOES H2020 project datasets. This is combined with scenario data from the openENTRANCE Scenarios (**ID1b**). **Pack 2** is built by econometric tools and data combinations following the work of Gils (2014), but adapting this work to specify the practical potential for demand flexibility, as opposed to the theoretical potential, as explained at the beginning of this section. Specifically, this will take the form of a freely available Python script, where the user can view and specify key assumptions and parameters with respect to human behaviour and demand flexibility, i.e. the willingness of households to allow for automated demand flexibility (where the grid operator turns on and off their appliances remotely). This script will generate demand response potentials that are specified as inputs into the plan4EU and EMPIRE models, OD1 and OD2, respectively, and related cost parameters, from Figure 7. This output will be put on the openENTRANCE database via API and based on the common nomenclature and data template. **OD1** and **OD2** are converted to the **Common data format** using **T4**, which produces **Pack2.**
2. **Exchanging between Model 1 and Model 2**: Data from **Pack2** (produced by **Model 1**) are downloaded and converted to **Model 2** format using **T2** => **ID2c.**
3. **Exchanging between Model 1 and Model 3**: Data from **Pack2** (produced by **Model 1**) are downloaded and converted to **Model 3** format using **T3** => **ID3c.**
4. **Building Model 3 Input dataset and running Model 3:** The Model 3's dataset is built out of Model 3 own data (**ID3a**) and openENTRANCE database (**ID3b and ID3c**). Model 3 is executed and produces outputs. **OD3** is the part of the outputs that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD3** is converted to the **Common data format** using **T5**, which produces **Pack3.**
5. **Exchanging between Model 3 and Model 2**: Data from **Pack3** (produced by **Model 2**) are downloaded and converted to **Model 2** format using **T2** => **ID2d.**
6. **Building Model 2 Input dataset and running Model 2:** The Model 2's dataset is built out of Model 2 own data (**ID2a**) and openENTRANCE database (**ID2b, ID2c and ID2d**). Model 2 is executed and produces outputs. **OD4** is the part of the outputs that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD4** is converted to the **Common data format** using **T6**, which produces **Pack4.**

7. Expert analysis of outputs will determine takeaways from the study, model comparison, and policy recommendations for implementing residential demand flexibility in the electricity system. Within this process the findings from each of the system models (EMPIRE and plan4EU) with respect to the impacts of demand flexibilities will be compared side-by-side, supplemented with a side-by-side comparison of the assumptions and underlying structures of these two models which may lead to varied findings.

3.1.10 Implementation in the openENTRANCE scenario Explorer (screenshot)



Timeseries variables: Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning ×

Variable	Unit	Scale
Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning	MW	Linear (per unit)

Figure 8: Screenshot of OD1 data (Fig. 8) from Micro-econometric models. These are annual avg. Demand response potentials from Air Conditioners in each NUTS-2 region.

Figure 8 shows a snapshot of an initial data upload to the openENTRANCE scenario explorer from CS1 micro-econometric models. The Figure shows the avg. technical potential for MW demand response load shifting in the representative hour for each NUTS-2 region. Heterogeneity across regions is mainly driven by the number of households in regions, and the ownership of air conditioning, which is in turn driven by prevailing temperatures and household incomes. Final data will be at the hourly resolution and include up to 10 household technologies; this figure is given as a proof of concept.

3.2 Case Study 2 - Behaviour of communities of actors

3.2.1 Case study objectives, challenge and beyond the state of the art

The concept of optimizing local solar PV self-generation and consumption on the 'prosumers' level is already well established in many European countries. Going beyond individual prosumer boundaries to neighbourhood and district level and introducing so-called energy communities is explicitly mentioned in the 'EC Clean Energy Package' (the establishment of energy communities and further 'democratization' of the energy system). Within the boundaries of a building, the legal framework already exists in some countries (e.g. Austria, Germany). In this case study, the sharing of solar PV generation is also going beyond the meter and beyond the boundaries of a closed system (no microgrids).

The members/actors of the communities are characterized by an individual willingness-to-pay for local PV generation from the community. Participation is on a voluntary basis, so this is fully democratic participation, considering the individual needs of the actors. The actors involved can be regular households or small businesses (small and medium-sized enterprises – SMEs), with different demographic backgrounds and different individual objectives.

The aspects considered are widely manifold, for example in terms of renewable technologies involved or system boundaries (spatial extent, distribution grid anatomy, peer-to-peer matching/trading in a wider context, etc.). The community does not intend to be self-sufficient, but:

- The self-consumption (solar PV and battery storage) of the energy community as a whole is maximized
- Solar PV generation is allocated within the community according to each prosumer's willingness-to-pay for renewable electricity generation

Challenges and beyond state of the art:

- Individual willingness-to-pay of different actors involved: This takes into account the social aspects and behaviour of the actors involved
- No closed system (the energy communities are part of the local distribution grid)
- Analysing different settlement patterns and upscaling the potential for energy communities for a whole country
- Upscaling the community potential for Europe as a whole

3.2.2 Detailed methodology of the case study - modus operandi

1-Defining the communities:

To increase PV systems' profitability, a high share of self-consumption is key. By aggregating the load of multiple prosumers or consumers and by sharing of PV generation, the cumulative self-consumption can be increased. Together, the prosumers and consumers are forming a community of actors, jointly operating the renewable generation. In this case study, a techno-economic linear optimization model will be applied to the community set-up to allocate PV generation between the members of the community.

The first step of this case study will be the definition of the different system boundaries of local energy communities, starting from a single prosumer. The different concepts include shared local energy management (matching renewable electricity self-generation and consumption, supported by battery storage) within a:

- multi-apartment building,
- a local neighbourhood/district,
- a small village.

The technology portfolio includes:

- PV (rooftop, building integrated, small-scale ground mounted)
- supported by small battery storage

2-Defining actors and settlement patterns:

Set-ups in terms of actor portfolios, e.g.

- tenant/owner structure multi-apartment building,
- building/population/small businesses structure in a village

Considering also diversity of settlement patterns in

- dense cities,
- sub-urban and
- rural areas.

In that sense, the individual actors and their behaviour are considered. Demand profiles, available/suitable roof top area for PV and social aspects are included. In addition, the individual objectives of the actors to join the community are determined (e.g. maximizing local self-generation, minimizing electricity purchase costs, avoiding emissions and/or externalities). The model applied in this case study, FRESH:COM, is considering these aspects. The results of the modelling work include detailed hourly time series of electricity generation and consumption, battery storage operation, and PV sharing within the energy community on prosumer level (single actor) and community level. The optimal community set-up (actors involved, size, renewable generation capacity) is also evaluated, considering dynamic phase-in and phase-out of prosumers of the community.

3-Determining the energy community potential for Austria:

In terms of geographic coverage, a thorough quantitative assessment of the short- and long-term local energy community potential is planned for Austria by investigating the profitability and optimal installed capacities of PV systems for energy communities (considering several important structural indicators such as settlement patterns, demographics, and regional differences, which are necessary to describe the communities in a tailor-made metrics).

4-Determining the energy community potential for 4 reference countries in Europe

On higher aggregation level (in terms of empirical indicators necessary to describe the communities) additional 4 European 'reference countries' (representing e.g. the Iberian Peninsula, South-Eastern Europe, UK, Scandinavia) are also quantitatively analysed. The potential for local energy communities (optimal installed PV capacities for PV sharing within communities) is evaluated for each of those countries

5-Upscaling on European level

By knowing the energy community potential of the European reference countries, a quantitative upscaling of the short- and long-term local energy community potential is conducted for Europe as a whole, again using a metrics with a variety of country-specific structural and energy sector-related data as well as assessments in terms of different barriers, different in nature (technical, economical, regulatory, etc.). In the end, these metrics are matched with the countries where detailed quantitative results have been computed and checked for their plausibility.

3.2.3 Expected results and limitations

In the case study, quantitative analyses of local energy communities are conducted. There are results for different types of community set-ups varying in size, technologies involved, and settlement pattern/demographic situation. The main output of results is

- Determination of the net present value of investment and operational results up to 15 years
- Analyses for Austria and 4 European 'reference countries'
- Quantitative upscaling of the short- and long-term local energy community potential is conducted for Europe as a whole

Specific results

The specific results of the case study are in respect to the individual actors of the community as hourly time series as well as on annual basis. Details on the community set-up (e.g. capacities of different technology types) are presented as well.

- Optimal design of the renewable technology portfolio for the community
- Time series of total and shared hourly local generation, storage operation, demand, and purchases from the public grid
    - For each community actor

  - For the community as a whole

- Revenues streams of community actors, distribution grid operator, and external supplier
  - Sustainable business model making

Limitations

The following aspects are limitations of the model and the case study:

- The only energy carrier is electricity: This limitation does not allow sector coupling to be considered.
- The model is a techno-economic model, not considering the physical power flow within the community. The transaction between the members of the community is a peer-to-peer trading/matching mechanism.

3.2.4 Set of Models

Table 3. Sample of format the set of models

Models	Lead Partner	Main Objective
FRESH:COM	TU Wien	Maximizing the social welfare of an energy community: Maximizing the self-consumption of the community as a whole and optimally allocating PV generation within the community

Table 4. Sample of format for the summary of model requirements

	Geography		Time		Technological scope
	Horizon	Granularity	Horizon	Granularity	
FRESH:COM	EU27+NOR/CH	Local, community level	One year	Hourly	• PV generation • Battery storage • Electricity

This section adds further information about the models used in the case study. A detailed description is shown in Perger et al (2020)[13].

Model type and problem:

The local energy community model FRESH:COM (FaiR Energy Sharing in local COMmunities) will be used. The modelling approach is as follows:

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[13] T. Perger, L. Wachter, A. Fleischhacker, H. Auer, *PV Sharing in Local Communities: Peer-to-Peer Trading under Consideration of the Prosumers' Willingness-to-Pay*, in Sustainable Cities and Society (2020), *under review*

- Implementation of the linear optimization tool FRESH:COM in Python using Pyomo and Gurobi
- The allocation mechanism is considering the prosumers'/actors' individual willingness-to-pay while simultaneously maximizing the community's self-consumption
- Conducting an optimal techno-economic design of the local renewable technology portfolio (PV system, battery storage) depending on the composition of community actors (described by the individual characteristic load profiles)
- Different allocation and clearing mechanisms of shared local generation:

  1.) static (individual actor's optimum according to predefined allocation scheme)

  2.) dynamic (hourly/real time global community optimum exploiting several synergies among actors' load profiles and preferences)
- Studying a variety of energy community patterns and set-ups (incl. annual phase-in and phase-out of community actors resulting in frequent reallocations of the default set-up)

Input data

The FRESH:COM model will have the following parameters as input data:

Parameter	Description	Unit	Spatial		Temporal	
			Granularity	Flexibility	Granularity	Flexibility
Electricity Demand	Electricity demand profile for members of the community	kWh	End user	**From:** Country **Until:** End user	Hourly	**From:** yearly **Until:** hourly
PV generation	PV generation profile for members of the community	kWh	End user	**From:** Country **Until:** End user	Hourly	**From:** yearly **Until:** hourly
Battery capacities	Maximum state of charge of each battery in the community	kWh	End user	End user		
Battery maximum power	Maximum (dis)charging power of each battery in the community	kW	End user	End user		
Retail electricity price	Average retail electricity price of a country for a year	EUR/kWh	Country	Country	Yearly	Yearly
Spot market electricity price	Average spot market electricity price of a country for a year	EUR/MWh	Country	Country	Yearly	Yearly
Marginal emissions	Marginal emissions of a country's electricity system	kgCO2/kWh	Country	Country	Hourly	**From:** yearly **Until:** hourly

Willingness-to-pay	Individual willingness-to-pay of the members of the community for PV generation	EUR/t CO2	End user	End user	Yearly	Yearly

Output data

The FRESH:COM model will have the following as output variables:

Variable	Description	Unit	Spatial		Temporal	
			Granularity	Flexibility	Granularity	Flexibility
Traded electricity	Electricity traded within the community	kWh	End user	**From:** Country **Until:** End user	Hourly	**From:** yearly **Until:** hourly
Purchasing electricity	Purchasing electricity from the retailer	kWh	End user	**From:** Country **Until:** End user	Hourly	**From:** yearly **Until:** hourly
Selling electricity	Selling electricity to the grid	kWh	End user	**From:** Country **Until:** End user	Hourly	**From:** yearly **Until:** hourly
Battery state of charge	State of charge of each battery in the community	kWh	End user	End user	Hourly	Hourly
Battery (dis)charging	(Dis)charging of each battery in the community	kW	End user	End user	Hourly	**From:** yearly **Until:** hourly
Social welfare	Social welfare of the community (for the community as a whole and for the single prosumer)	EUR	End user	**From:** Country **Until:** End user	hourly	**From:** yearly **Until:** hourly
NPV	Net present value analyses of the energy community	EUR	End user	**From:** Country **Until:** End user	15-20 years	15-20 years
GHG emissions	GHG emissions of the community and emissions avoided/saved by the community	tCO2	End user	**From:** Country **Until:** End user	hourly	**From:** yearly **Until:** hourly
Community potential	Potential for energy communities on country level or for Europe as a whole	GW	Country	**From:** Europe **Until:** Country		

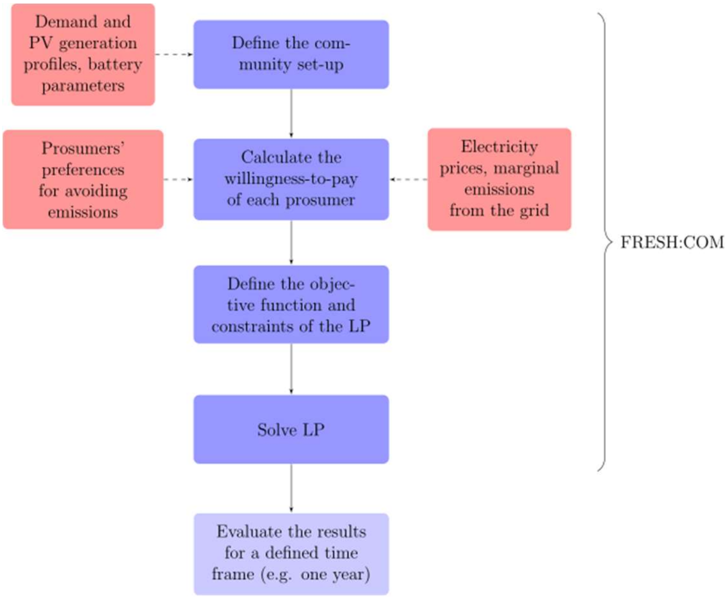

Figure 9: Schematic overview of FRESH:COM developed at TU Wien, from Perger et al (2020)[14].

3.2.5 Workflow of the case study

The figure below presents, in a clear and simple manner, the workflow of the case study.

Input

- ❑ Energy community set-up
- ❑ Country/Region
- ❑ Electricity demand profiles (time series)
- ❑ Prices (Retail electricity price, spot market price)
- ❑ Production and storage capacities
- ❑ PV time series
- ❑ Emission time series
- ❑ Prosumers' preferences

FRESH:COM

- ❑ FRESH:COM – FaiR Energy SHaring in local COMmunities
- ❑ Linear Optimization Model (LP)
- ❑ Social welfare maximization
  - ❑ Optimum for the community as a whole
  - ❑ Optimum the existing prosumers and potential new prosumers

Output

- ❑ Social welfare of the community
- ❑ Time series of electricity consumption and production
- ❑ Time series of peer-to-peer traded electricity
- ❑ Time series of battery storages (state of charge)
- ❑ NPV analyses of the community
- ❑ GHG emissions
- ❑ Energy community potential on country level or for Europe

Figure 10: Case study 2 general workflow

3.2.6 General list of data

The following data lists illustrate key data sets needed to analyse the case study and its source.

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[14] T. Perger, L. Wachter, A. Fleischhacker, H. Auer, *PV Sharing in Local Communities: Peer-to-Peer Trading under Consideration of the Prosumers' Willingness-to-Pay*, in Sustainable Cities and Society (2020), *under review*

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Electricity prices; Average retail electricity price for customers and average day-ahead spot market price
- Emission produced in the electricity system (Marginal emissions)

Data coming from modelling teams' own databases

- PV generation profiles
- Electricity demand profiles of prosumers : Households, and Small businesses/SMEs
- Battery storage technologies: Maximum capacities, Maximum (dis)charging power and Efficiency factor

Data produced during the case study exercise (mainly outputs of the model)

- PV generation traded within the community
- Social welfare of the community
- NPV analyses/ annuities of the community
- GHG-emissions of the community
- Evaluation of the energy community potential in: Austria and 4 European reference countries
- Upscaled evaluation of the energy community potential of Europe as a whole

3.2.7 Data workflow

To illustrate the details of the workflow in a general and specific way, we use the example in Figure 11. Facts that are illustrated in the figure:

- The openENTRANCE database provides scenario information.
- There is one model that receives information from the database and outside the database
- There are tools to convert the data format that comes from each model to Common Data Format of the database and vice versa.
- Dashed lines represent the flow of information

It is considered 3 types of dataPacks:

- Whose content comes from openENTRANCE scenarios (**Pack1**)
- Whose content comes from the FRESH:COM database
- Whose content comes from FRESH:COM output (**Pack2**) and is uploaded to the openENTRANCE database

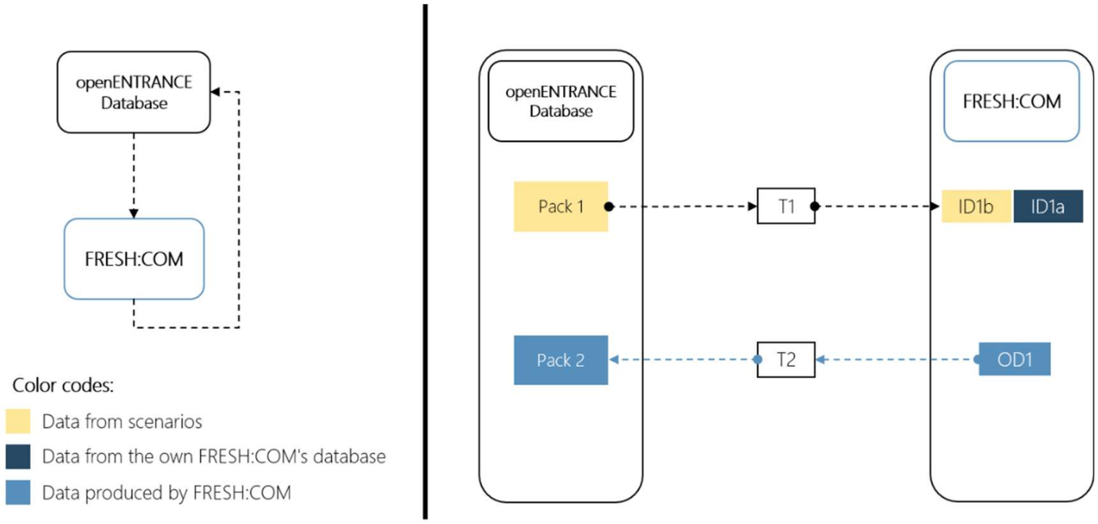


Figure 11: Data workflow

dataPack	Data flow	Content, as example:
Pack 1	Input data from scenarios	Electricity prices (Retail electricity prices, spot market prices) Emissions for electricity generation
Pack 2	Output data from FRESH:COM	Social welfare of the community NPV analyses/ annuities GHG emissions produced and avoided Energy community potential for reference country/Europe

List of Datasets (using FRESH:COM own format):

ID1a	Input dataset **"part a"** that comes from the own **FRESH:COM** database, *i.e.* ***Demand profiles***, *etc.*
ID1b	Input dataset **"part b"** that comes from the openENTRANCE database to **FRESH:COM**, *i.e. electricity prices, etc.*
OD1	Output dataset from **FRESH:COM** to openENTRANCE database, *i.e. Energy community potential on country level, etc.*

3.2.8 Data-exchange tools

An example list is provided below:

T1 (OE-FRESH:COM)	Set of tools or methods to convert data from the **Common data format** to **FRESH:COM format**

T2 (FRESH:COM-OE)	Set of tools or methods to convert data from **FRESH:COM output format** to **Common data format**

3.2.9 Execution order

This section provides the stepwise plan to carry out the case study, specifying the data exchanged (with the relevant data-exchange tools if appropriate):

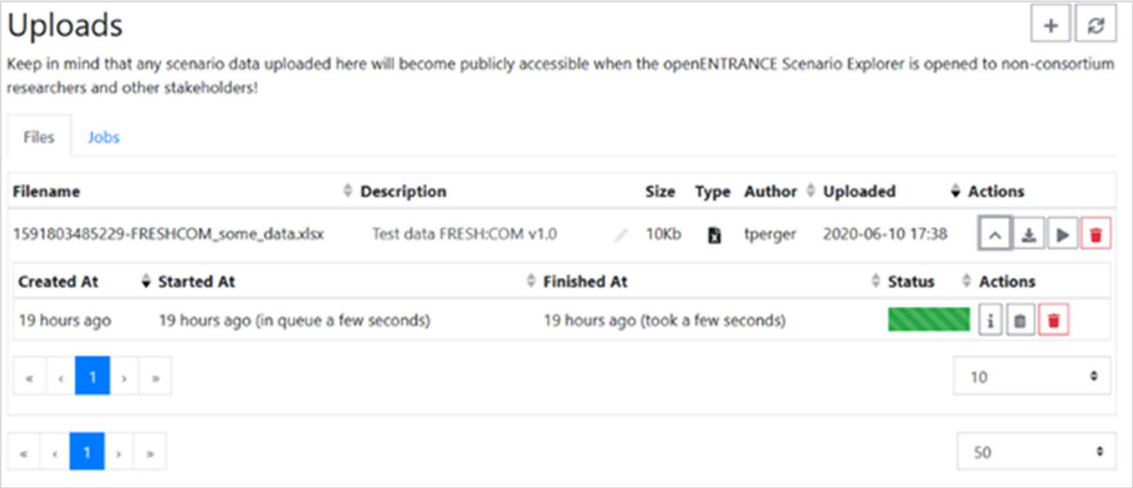
1. **Extraction of data from openENTRANCE Database:** First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T1** into **FRESH:COM** data format **ID1b.**

2. **Building FRESH:COM Input dataset and running FRESH:COM:** The FRESH:COM dataset is built out of FRESH:COM own data (**ID1a**) and openENTRANCE Scenario data (**ID1b**)**.** FRESH:COM is executed and produces outputs mainly using the *Python* package *pandas*. **OD1** is the part of the output that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD1** is converted to the **Common data format** using **T2**, which produces **Pack2.**

3. **The case study's output and results are uploaded to the OpenENTRANCE scenario explorer.**

3.2.10 Implementation in the openENTRANCE scenario Explorer (screenshot)

A file containing first results of the case study (model version FRESH:COM v1.0) was uploaded to the openENTRANCE Scenario Explorer:



Uploads

Keep in mind that any scenario data uploaded here will become publicly accessible when the openENTRANCE Scenario Explorer is opened to non-consortium researchers and other stakeholders!

Filename	Description	Size	Type	Author	Uploaded	Actions
1591803485229-FRESHCOM_some_data.xlsx	Test data FRESH:COM v1.0	10Kb		tperger	2020-06-10 17:38	

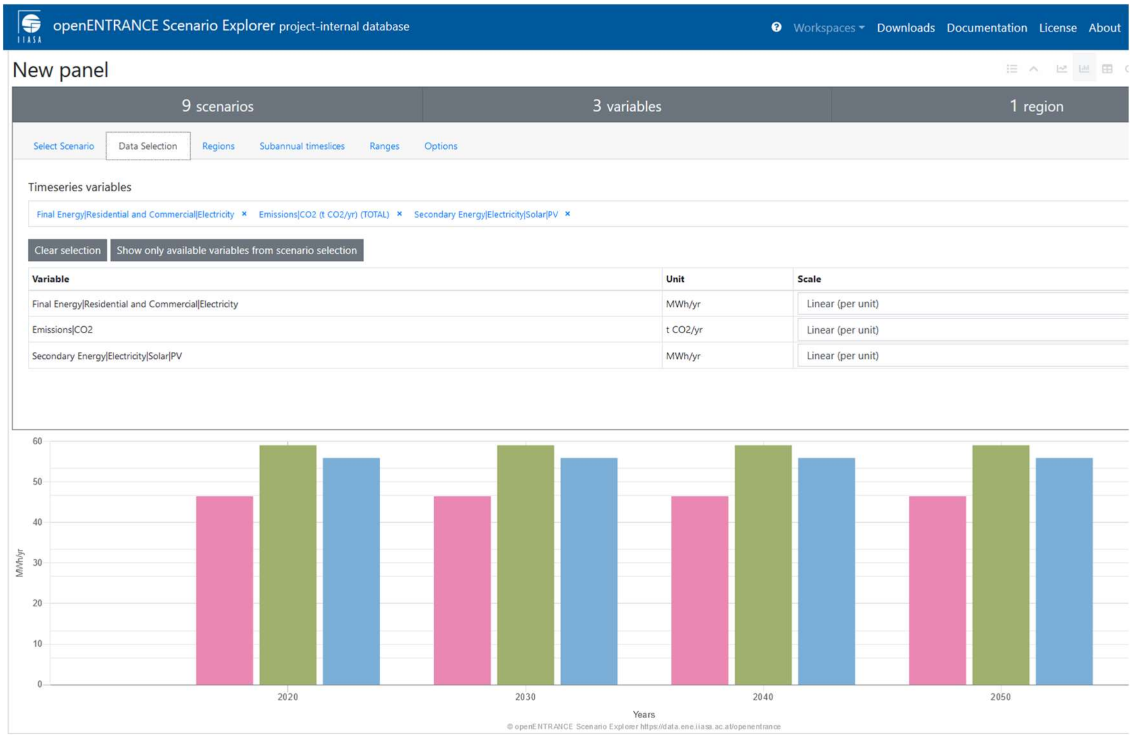
Created At	Started At	Finished At	Status	Actions
19 hours ago	19 hours ago (in queue a few seconds)	19 hours ago (took a few seconds)	🟩	

« ‹ 1 › » 10

« ‹ 1 › » 50

Figure 12: FRESH:COM model upload data versions

Before uploading, the file was thoroughly checked if the openENTRANCE nomenclature is followed. A workspace was created to visualize some of the data uploaded.



Variable	Unit	Scale
Final Energy|Residential and Commercial|Electricity	MWh/yr	Linear (per unit)
Emissions|CO2	t CO2/yr	Linear (per unit)
Secondary Energy|Electricity|Solar|PV	MWh/yr	Linear (per unit)

Figure 13: FRESH:COM model results in the openENTRANCE scenario explorer

3.3 Case Study 3: Need of flexibility - Storage

3.3.1 Overall objective and case-study baseline

Electricity storage is one of the key supporting technologies of the energy transition, as it provides flexibility and thus is needed to facilitate the integration of renewables. Several technologies could be deployed in this context. Pumped-storage hydro is a mature technology with low investment costs for relatively large sizes, but long and difficult (in some cases, impossible) installation of new capacity. However, although there are already significant hydro storage and pumped-hydro storage capacities installed in different regions across Europe, there is still potential to further invest and increase these capacities. In many cases, building new storage is not possible, but there is potential for upgrades (e.g. adding a pumping mode to HS plants). Some of these projects are already in the PCI list (Projects of Common Interest). The maximum stored energy in the present reservoirs in some European countries can be summarized as follows[15] (all Numbers in TWh): Norway (85), Sweden (34), Spain (18.4), Switzerland (8.4), Austria (3.2) and France (9.8). Norway has hardly any pumping capacity in its present system. However, a recent study has shown that it is possible within present regulations (water-flows and levels in reservoirs) to install about 20 GW in the South-Western part of the country. The pumped-storage hydropower can contribute to balance variable wind and solar power production in UK and Germany/Benelux if the transmission capacities are increased.

At the other side of the spectrum, batteries could offer an alternative to complement hydro with smaller (often at the scale of a single consumer), decentralized storage, albeit at a higher current cost. In addition, the differing sizes of these technologies mean that they can be used at different time horizons and levels in the system: while pumping stations with large sizes in terms of energy content (capacities) could be used to shift loads over the weekend periods or even seasons, the smaller batteries could only be used for several hours. In addition, smaller batteries would not be completely controllable by the system operator and would rather respond to the needs and behaviour of consumers. These different operational strategies have a technical and economic aspect and can be seen as a further specification of battery capacities. The different operation strategies run along the

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[15] Lehner B, Czisch G, Vassolo S, Europe's hydropower potential today and in the future. Eurowasser, 2013

so-called Pareto Front[16] (e.g. profit maximization and self-consumption can be seen as extreme values in a multi-dimensional presentation). Therefore, the use of the batteries is first calculated taking into account minimum costs. This solution also includes a corresponding proportion of local self-consumption. The calculated minimum costs are relaxed by alpha and taken into account as an additional constraint. Subsequently, the costs are no longer minimized but local self-consumption is maximized. The following figure shows the approach, where the two criteria cost and level of self-consumption determine the Pareto Front.

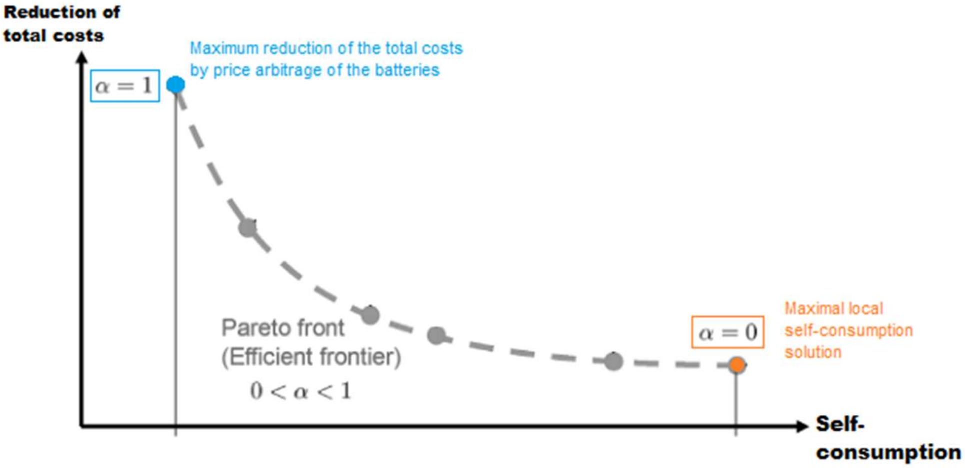

Figure 14: Correlation between the reduction of total costs and local self-consumption. The operation strategy pursuing the price arbitrage of batteries reduces the total costs maximally.

As seen, both technologies represent different avenues for the use of storage. On the one hand, batteries have traditionally been associated to smoothing short-term fluctuations in demand or renewable generation (e.g. compliance with the registered feed-in profile of renewable energy sources, such as wind power plants or storing photovoltaic generation to increase local self-consumption). Their size is directly related to the scope of this smoothing: smaller batteries support a single consumer, while larger ones can minimize the local power excess or deficits of a community over longer time periods. Therefore, battery supports the relative independence of prosumers and is linked to the development of decentralized structures in energy markets. Large-scale pumped-hydro, on the other hand, can be used to balance renewables at the European level. These two alternative uses of storage and schemes of centralization/decentralization will lead to diverging needs for market integration, which will be reflected in transmission network needs.

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[16] Multi-objective optimization is an area of optimization involving more than one objective function to be optimized simultaneously. In this term, der Pareto Front shows the most efficient solutions concerning both objective functions, profit, and self-consumption maximization. As usual, there exist multiple Pareto optimal solutions.

Hence, the main objective of this case study is the analysis of the widespread deployment of pumped-hydro storage and batteries in terms of system operation costs and transmission network development. Several options for the upscaling of pumped-hydro storage will be considered in combination with the wide-scale adoption of small-scale batteries. For the latter, several operation strategies will be considered[17]:

1) profit maximization[18] by single consumers, communities, or companies

2) minimization of local excess-deficit by prosumers

3) Load following by using battery storage capacities - this includes dumb or smart EV charging

In 1), the profit maximization by different market participants is achieved by the exploitation of arbitrage mainly due to price signals (off-peak and on-peak) of day-ahead and intraday market pricing. This operational strategy does not consider the self-consumption of the prosumers in the energy community albeit local self-consumption operation of the battery storage can be economic. Thereby, the understanding of battery storage from a purely economic perspective is developed. This operation strategy signifies one maximum value of the so-called "Pareto Front".

In 2), the minimization of local excess-deficit by prosumers also enables reducing total system costs. However, this operation strategy aims for a maximum of local self-consumption in the energy community or different types of prosumers. The optimization of the local share of renewable generation is considered throughout the energy system (as a result the energy system is built out of nodes, whereby the local self-consumption of all nodes in sum is maximized). Thus, the maximized local share reduces the excess-deficit by prosumers.

In 3), the third operational strategy addresses generation and load following. Thereby, the battery storage adapts its output to the needs of the supply of the demand (adjust its power output as demand for electricity fluctuates). Hence, the battery storage act in terms of satisfying the demand as a production unit. In this way, schedule compliance for the declared generation and biddings can be ensured and the need for balancing energy reduced.

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[17] In the following, the operational strategies to maximize profit by prosumers, to minimize local excess-deficit by prosumers, and the strategy for load following are examined precisely. However, further operation strategies are possible. For example, the utilization of battery storage as a reserve for balancing energy. Besides, storage can be used to increase the stability of network services (e.g. prevention of overvoltage). Nevertheless, these further two strategies are out of scope of this case study because results would not quantitatively apparent.

[18] In this term, the investigation of the minimization of the total costs can be seen as the dual problem of optimization as a characteristic of modelling. Hence, the solution of the optimization in terms of maximizing profit is the same as in terms of minimizing total costs.

In parallel, the different charging strategies and options of electrical vehicles (EV) expand the range of battery storage in terms of flexibilities. In the case of a dumb charging strategy, the battery capacities can be seen as an additional very rigid load profile. No flexibilities can be achieved by loading batteries. However, the smart charging of EV can be implemented to maximize local self-consumption or minimize the total costs of supply due to the arbitrage of price signals. Thus, we factor the dumb or smart charging operation of EV into the three above explained operational strategies.

Furthermore, merging prosumers into representative energy communities (e.g. through the application of settlement patterns) on the level of microgrids enable the investigation of utilization rates of distribution grids and can be used for upscaling to provincial or country level. This is made possible by the formation of typical building classes (e.g. large-panel system buildings, apartment buildings, and single-family houses). The area under consideration can therefore be represented sufficiently accurately by typical building clusters.

The analyses will contemplate different time scales (seasonal, weekly, daily), associated with different storage capacities.

The case study will focus on two regions where the possibilities of these technologies are particularly interesting: The Iberian Peninsula and the Nordic countries. However, the analyses will consider the impact of these developments at a European level. This means that, in order to keep the calculations manageable, the focus regions will be studied in detail, while the rest of Europe will be represented at an aggregate level.

3.3.2 Challenges and beyond the state of the art

A multitude of studies have focused on the potential of battery storage for improving the flexibility of the system and for increasing renewable penetration. However, the trade-offs between different technologies are only beginning to be explored. Furthermore, most studies focus on a relatively small region, so that large-scale benefits remain undetected. In this case study, we would like to incorporate all the key elements of the problem so that their combined effects can be assessed as accurately as possible:

- **Hydro storage vs. batteries**: both technologies bring the flexibility of storage to the system albeit with opposing profiles in terms of market integration needs.
- **Versus or synergies of the grid and battery:** in general, all options for flexibility are competing with each other. As mentioned above, both, grid infrastructure and battery storage enable flexibility but also can reveal synergies depending on the implementation, the network topology, and the network congestions/bottlenecks. In this context, the optimal grid expansion to use synergies between grid infrastructure and battery storage is needed, whereby the three different operational strategies also influence the examination.

- **Consideration of different strategies for battery use:** the impact of battery storage will be greatly affected by the strategy that is followed in its use, for instance, whether it corresponds to a profit maximization rule or to minimize excess or defect for prosumers or small communities.
- **The local vs. the regional:** we model the strategies at the prosumer level and calculate impacts at the European level. In order to be able to calculate them, we model our focus regions in a detailed manner and keep an aggregate description of the remaining of the EU.
- **The short vs. the long term:** our analyses include several time horizons that span from hours to a year, so that the profiles of different technologies can be taken into account.
- **A detailed model for transmission**: the impact on transmission network needs will be assessed by means of a detailed model that considers the physics of power flows.

Including all these elements will enable us to provide a comprehensive perspective on the effects of the large-scale deployment of storage at the European level.

3.3.3 Expected results and limitations

Each of the storage-deployment scenarios will represent a combination of hydro-storage, batteries, and their operation strategy. For each of these, we will calculate the optimal operation of the power system, at aggregate and local level, and its associated cost. In addition, we will compute the corresponding optimal development of the transmission network and its cost. The interactions between the scenario-defining elements will be explored. These results will illustrate the potential advantages of these storage technologies and highlight possible synergies.

The main limitations of the study will be linked to the simplifications carried out in the definition of scenarios and system planning and operation. One particular example is that EMPS/MAD does not consider any uses for water that are not purely the generation of electricity. This means that some ecological constraints that can be particularly relevant in small units (i.e. run-of-the-river flows). In addition, HERO&OSCARS enables a high resolution in two dimensions: spatial and temporal. However, to limit calculation time, the clustering algorithm[19] for both dimensions abstract the reality. Thus, information on the energy community and on the country level cannot be modelled in detail.

3.3.4 Detailed methodology of the case study: modus operandi

The case study will be structured as a comparative analysis, across two different dimensions:

- Level of deployment of storage, which will consider several situations for the upscaling of hydro pumping and batteries. This will assess the flexibility they can provide for the system comparing their performance and evaluating their synergies.
- Operating strategy associated to the agent in charge of the operation of the batteries. This will include an analysis of the types of agents involved and their multiple utilization

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[19] The yearly times series (temporal dimension) are represented by characteristic weeks. Settlement patterns are used to cover geographical aspects (spatial dimension) of the energy communities.

objectives: single consumers, communities (e.g. municipalities), or small companies operating storage for maximum profit and other entities that can take into account physical prosumer energy management (e.g. mitigation of local generation excess/deficit) or electric vehicle charging management. The different operating strategies will be translated into output curves (e.g. charging/discharging patterns) that describe the use of storage[20]. In addition, the Pareto Front in the three dimensions/operation strategies is a result, to display multi-criteria optimization[21]. In order to limit the number of scenarios, only the extreme points of the Pareto Front are further examined in the following analyses.

The effectiveness of storage deployment and utilization will, in this case study, be measured as reduced needs for transmission network expansion and reduced overall system costs. Pumped hydro and batteries provide the same functionality at different levels in the system and we will observe the impact on transmission network expansion.

For each considered deployment possibility, the model EMPS/MAD will calculate the optimal medium-to-short-term operation of the system, which implies solving the hydrothermal coordination problem at the European level considering a detailed model for focus regions (that is, the Iberian Peninsula and Norway) and an aggregate perspective for the remaining countries. Then, the models OSCARS/HERO will be employed to compute the optimal operation of battery storage based on the electricity prices generated by EMPS/MAD. The operation of these battery storage devices will be represented through output curves (e.g. temporal course of the state of charge). Then, the model openTEPES will take the operation of both pumped hydro and battery storage to determine the optimal expansion of the transmission network needed to provide additional flexibility in the form of an increase in the level of integration across markets. Subsequently, the new transmission network will be fed back to EMPS/MAD, which will adapt the operation of hydro storage and the system to take into account the new transmission lines. EMPS/MAD will produce new electricity prices to be considered by OSCARS/HERO to compute new battery operation output curves, to be considered by openTEPES together with the new operation of pumped hydro. The process will iterate among EMPS/MAD, OSCARS/HERO, and openTEPES to ensure the stability of results indicated as convergence[22].

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[20] Furthermore, KPIs in terms of specific marginal emissions and changing load profiles over time are developed.

[21] The examination of the Pareto Front in the three dimensions enables investigation, which is beyond the Master/Slave principle (Corresponding to the list on page 2). The solution in-between the maximum values represent intermediate operation strategies.

[22] From the perspective of the different operational strategies of battery storage, the convergence might be achieved in the dependence of the Pareto Front and its curvature and radius of curvature respectively. Based on this a termination criterion can be described (e.g. taking the plane course into account).

3.3.5 Set of models

Table 5. Sample of format the set of models

Models	**Lead Partner**	**Main Objective**
EMPS&MAD	SINTEF	Long-to-medium term operation of hydrothermal power systems
HERO	TU WIEN	Optimal capacity allocation and dispatch of distributed generation and battery storage for meeting the energy services needs in communities
openTEPES	COMILLAS	To determine the investments plans of new facilities for supplying the forecasted demand at minimum cost
OSCARS	TU WIEN	Optimal utilization of small battery storage systems at prosumer level

Table 6. Sample of format for the summary of models requirements

	Geography		Time		Technological scope
	Horizon	**Granularity**	**Horizon**	**Granularity**	
EMPS &MAD	Iberian Peninsula (ES + PT) & Norway	NUTS2 (Province)	1 year (2050)	Each 2 or 3 hours of Time Step. Hourly is possible (weekly for water values)	• Biomass • Coal • Cogeneration • Combined Cycle Gas Turbine (CCGT) • Demand Response • Energy Storage System (ESS) • Geothermal • Hydro Power • Lignite • Nuclear • Oil • Power Transmission • Pumped-Hydro Storage (PHS) • Solar PV Utility • Solar Thermal (CSP) • Wind Offshore • Wind Onshore
HERO	Iberian Peninsula (ES + PT) & Norway	NUTS3 (District) & Community	1 year (2050)	Hourly	• Energy Storage System (ESS) • Sector coupling (electricity, heating and cooling, passenger mobility[23]) • Different operational strategies for battery storage • Solar PV Rooftop and Utility • Wind On- and Offshore • Load following (smoothing the demand curve) and Demand side management (DSM) • Geothermal sources, biomass and bioenergy, micro-CHP

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[23] Notably dumb and smart EV charging

openTEPES	Iberian Peninsula (ES + PT) & Norway	NUTS2 (Province)	1 year (2050)	Hourly (weekly for water values)	Biomass Coal Cogeneration Combined Cycle Gas Turbine (CCGT) Energy Storage System (ESS) Geothermal Hydro Power Lignite Nuclear Oil Power Transmission Pumped-Hydro Storage (PHS) Solar PV Utility Solar Thermal (CSP) Wind Offshore Wind Onshore
OSCARS	Iberian Peninsula (ES + PT) & Norway	Community & End User	1 year (2050)	Hourly	Energy Community Prosumers Energy Storage System (ESS) High share of local self-consumption Solar PV Rooftop and Utility Profit maximization

Model type and problem:

The case study will pivot between several models that, together, will be able to provide the necessary details of system planning and operation. EMPS&MAD will undertake the general definition of the hydrothermal systems studied, while HERO and OSCARS will deal with the deployment and optimal use of storage under several different strategies and TEPES will incorporate the impact of the transmission grid, which can enable the long-range use of resources across the European Union.

- **EMPS&MAD**: Computation of the **long-to-medium term operation of hydrothermal power Systems**
    - Optimal dispatch considering stochastic weather-related variables: wind and solar gross output and inflows to hydropower reservoirs
    - Manages separately individual water reservoirs computing individual water values
    - Considers aggregate power flow constraints (at corridor level)
- **HERO**: **Optimal capacity allocation and dispatch** (for distributed generation and energy storage) to meet the energy needs of **local communities**
    - Considers sector coupling (electricity, heating/cooling, and gas) at the distribution level
    - Enable high spatial and temporal resolution of energy systems

- **OSCARS: Optimal utilization of small batteries and flexible loads at prosumer level under various operation strategies**[24]
- **TEPES**: Computation of the **optimal expansion of large electricity transmission grids**
    - Network model with detailed granularity
    - Full representation of Kirchhoff laws and network losses
    - Both long and short-term uncertainty can be represented
    - Suitable for the analysis of the impact of the implementation of specific energy policies on the development of the transmission network.

The main data requirements for this case study are complete scenarios for:

Generation, with capacities per technology per region and costs in the case of thermal generation. In the case of hydro, the definition of reservoir structure, capacities and inflow scenarios will be needed, as well as their operation constraints. Gross power production scenarios for intermittent generation will also be needed. The expansion of generation will be calculated within the scope of the project by models such as GENeSYS-MOD, SCOPE or EMPIRE.

Demand, which includes the data that are needed to model prosumer strategies in OSCARS and HERO.

Transmission, which should include the starting network in a detailed manner for the focus regions and aggregated for the rest of the European Union.

Storage, data on all the storage units, or the equivalent aggregate ones to be represented in the analyses, need to be provided as well, including their injection/withdrawal capacity in terms of power and energy, and their efficiency.

Input data

Model	Variable	Description	Unit	Spatial		Temporal	
				Granularity	Flexibility	Granularity	Flexibility
EMPS &MAD	Power Demand	Demand in Active Power, can be total demand for a region or split in sub-groups as below	MW	NUT2 (Province)	**From:** country **Until:** NUTS2	Hourly	Typically, yearly demand plus weekly

---

[24] The model OSCARS enables superior operational strategies of storage (e.g. maximization of profit or local self-consumption of prosumers respectively). In principle, one possible strategy is to act and provide balancing energy. However, this utilization of battery storage is out of scope of this case study.

							and season profile
EMPS &MAD	Gas power capacities	Installed capacity of gas	MW	Per plant	**From:** clustered technology **Until:** per plant		
EMPS &MAD	Wind energy resources	Wind power production. A profile hour-by-hour is given by Wind Resources below	TWh	Per plant	**From:** clustered technology **Until:** per plant	Hourly	**From:** yearly **Until:** hourly
HERO	Temperature	Temperature	°C	End user	**From:** NUTS3 **Until:** End user	Hourly	**From:** yearly **Until:** hourly
HERO	Process capacity	Installed process capacity	MW	End user	**From:** Technology **Until:** End user		
openTEPES	Transmission capacity	Capacity of transmission lines	MW	Lines	**From:** Transfer capacity between regions **Until:** Lines		
openTEPES	Investment cost	Investment cost of transmission lines	MW	Lines	**From:** Transfer capacity (circuits) **Until:** Lines		
OSCARS	Electricity price	Average spot market price	EUR/MWh	NUTS3 (Districts)	**From:** NUTS3 **Until:** End user	Hourly	**From:** yearly **Until:** Hourly
OSCARS	Discharge of Batteries	Scheduled discharge of Battery Energy Storage Systems	MWh	NUTS3 (Districts)	**From:** NUTS2 **Until:** Lines	Hourly	**From:** yearly **Until:** Hourly

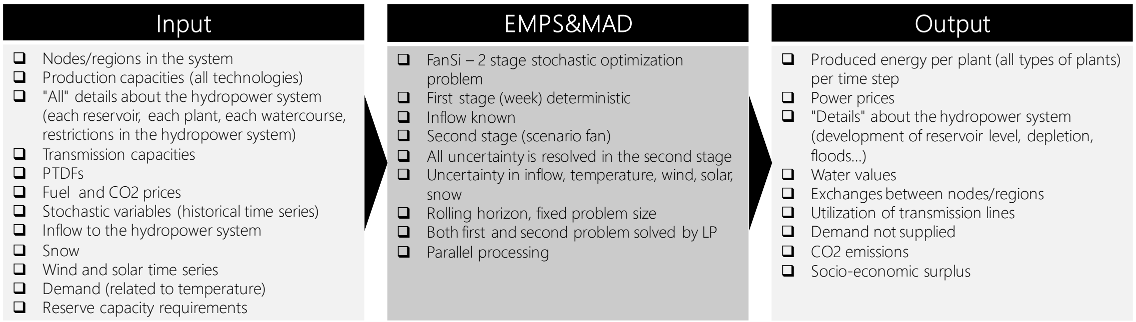
Output data

Model	Variable	Description	Unit	Spatial		Temporal	
				Granularity	**Flexibility**	**Granularity**	**Flexibility**

EMPS&MAD	Power Production	Produced energy per plant (all types of plants) per time step	MW	Per plant	**From:** clustered technology **Until:** per plant	Hourly	Per time step used in the specific project, typically 2-3 hours. Per hour is possible
EMPS&MAD	Reservoir level	Development of reservoir level	Mm3	Per reservoir	**From:** aggregated for all reservoirs in each region **Until:** per reservoir	Weekly	**From:** yearly **Until:** weekly
EMPS&MAD	Electricity price	Power price at spot market	Euro/MWh	NUTS2 (Province)	**From:** Country **Until:** NUTS2	Hourly	**From:** yearly **Until:** hourly
HERO	Heat demand	Temperature	MWh	End user	**From:** Community **Until:** End user	Hourly	**From:** yearly **Until:** hourly
HERO	CO2 emissions	Emissions of minimum cost solution	tCO2	End user	**From:** NUTS2 **Until:** End user	Hourly	**From:** yearly **Until:** hourly
openTEPES	Power flow	Power transmitted on a line	MW	Lines	**From:** Transfer capacity between regions **Until:** Lines	Hourly	**From:** yearly **Until:** hourly
openTEPES	Investment in lines	Candidate line installed or not	{0,1}	Lines	**From:** Transfer capacity between regions **Until:** Lines		
OSCARS	Storage level of ESS	Storage level of Battery Energy Storage Systems	MWh	End user	**From:** Community **Until:** End user	Hourly	**From:** yearly **Until:** Hourly

OSCARS	Spillage of wind resources	Spillage of wind power units	MWh	End user	**From:** Community **Until:** End user	Hourly	**From:** yearly **Until:** Hourly

The following figures present the models inputs and outputs.

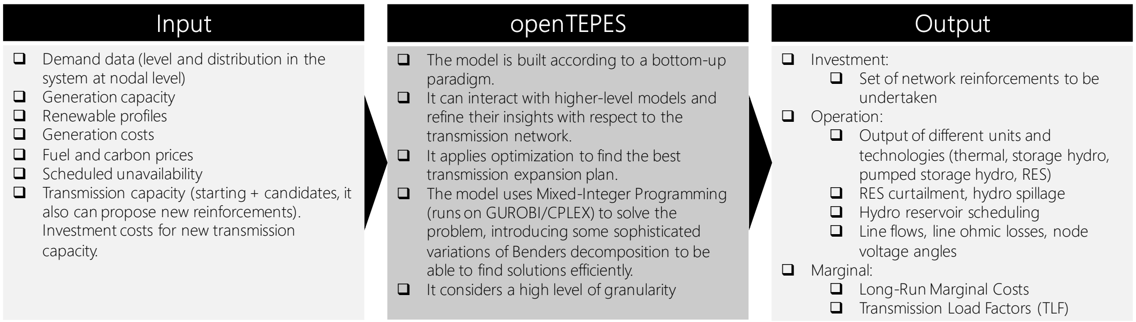


Input
- Nodes/regions in the system
- Production capacities (all technologies)
- "All" details about the hydropower system (each reservoir, each plant, each watercourse, restrictions in the hydropower system)
- Transmission capacities
- PTDFs
- Fuel and CO2 prices
- Stochastic variables (historical time series)
- Inflow to the hydropower system
- Snow
- Wind and solar time series
- Demand (related to temperature)
- Reserve capacity requirements

EMPS&MAD
- FanSi – 2 stage stochastic optimization problem
- First stage (week) deterministic
- Inflow known
- Second stage (scenario fan)
- All uncertainty is resolved in the second stage
- Uncertainty in inflow, temperature, wind, solar, snow
- Rolling horizon, fixed problem size
- Both first and second problem solved by LP
- Parallel processing

Output
- Produced energy per plant (all types of plants) per time step
- Power prices
- "Details" about the hydropower system (development of reservoir level, depletion, floods...)
- Water values
- Exchanges between nodes/regions
- Utilization of transmission lines
- Demand not supplied
- CO2 emissions
- Socio-economic surplus

Figure 15 : Schematic overview of the EMPS/MAD modelling framework developed at SINTEF.

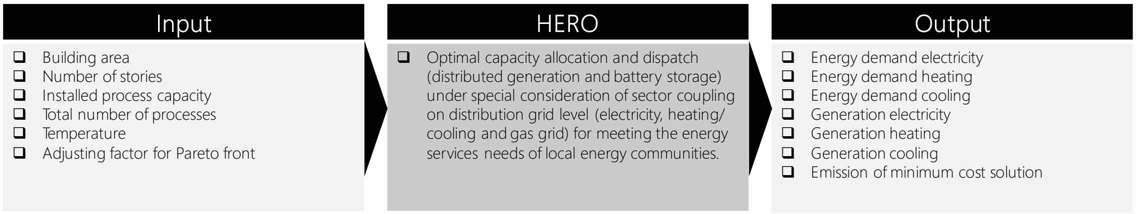


Input
- Demand data (level and distribution in the system at nodal level)
- Generation capacity
- Renewable profiles
- Generation costs
- Fuel and carbon prices
- Scheduled unavailability
- Transmission capacity (starting + candidates, it also can propose new reinforcements). Investment costs for new transmission capacity.

openTEPES
- The model is built according to a bottom-up paradigm.
- It can interact with higher-level models and refine their insights with respect to the transmission network.
- It applies optimization to find the best transmission expansion plan.
- The model uses Mixed-Integer Programming (runs on GUROBI/CPLEX) to solve the problem, introducing some sophisticated variations of Benders decomposition to be able to find solutions efficiently.
- It considers a high level of granularity

Output
- Investment:
  - Set of network reinforcements to be undertaken
- Operation:
  - Output of different units and technologies (thermal, storage hydro, pumped storage hydro, RES)
  - RES curtailment, hydro spillage
  - Hydro reservoir scheduling
  - Line flows, line ohmic losses, node voltage angles
- Marginal:
  - Long-Run Marginal Costs
  - Transmission Load Factors (TLF)

Figure 16 : Schematic overview of the openTEPES modelling framework developed at Institute for Research in Technology - Comillas Pontifical University.

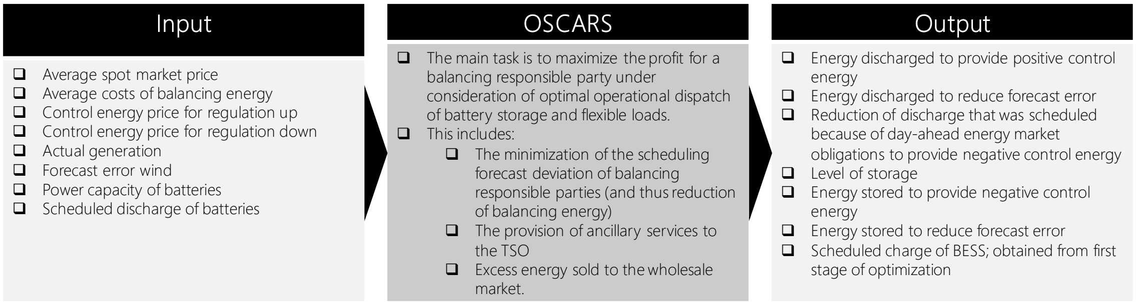


Input
- Building area
- Number of stories
- Installed process capacity
- Total number of processes
- Temperature
- Adjusting factor for Pareto front

HERO
- Optimal capacity allocation and dispatch (distributed generation and battery storage) under special consideration of sector coupling on distribution grid level (electricity, heating/ cooling and gas grid) for meeting the energy services needs of local energy communities.

Output
- Energy demand electricity
- Energy demand heating
- Energy demand cooling
- Generation electricity
- Generation heating
- Generation cooling
- Emission of minimum cost solution

Figure 17 : Schematic overview of the HERO modelling framework developed at TU WIEN.



Input

- ❑ Average spot market price
- ❑ Average costs of balancing energy
- ❑ Control energy price for regulation up
- ❑ Control energy price for regulation down
- ❑ Actual generation
- ❑ Forecast error wind
- ❑ Power capacity of batteries
- ❑ Scheduled discharge of batteries

OSCARS

- ❑ The main task is to maximize the profit for a balancing responsible party under consideration of optimal operational dispatch of battery storage and flexible loads.
- ❑ This includes:
  - ❑ The minimization of the scheduling forecast deviation of balancing responsible parties (and thus reduction of balancing energy)
  - ❑ The provision of ancillary services to the TSO
  - ❑ Excess energy sold to the wholesale market.

Output

- ❑ Energy discharged to provide positive control energy
- ❑ Energy discharged to reduce forecast error
- ❑ Reduction of discharge that was scheduled because of day-ahead energy market obligations to provide negative control energy
- ❑ Level of storage
- ❑ Energy stored to provide negative control energy
- ❑ Energy stored to reduce forecast error
- ❑ Scheduled charge of BESS; obtained from first stage of optimization

Figure 18 : Schematic overview of the OSCARS modelling framework developed at TU WIEN.

3.3.6 Workflow of the case study

The following figures show the workflow and models interactions in the case study.

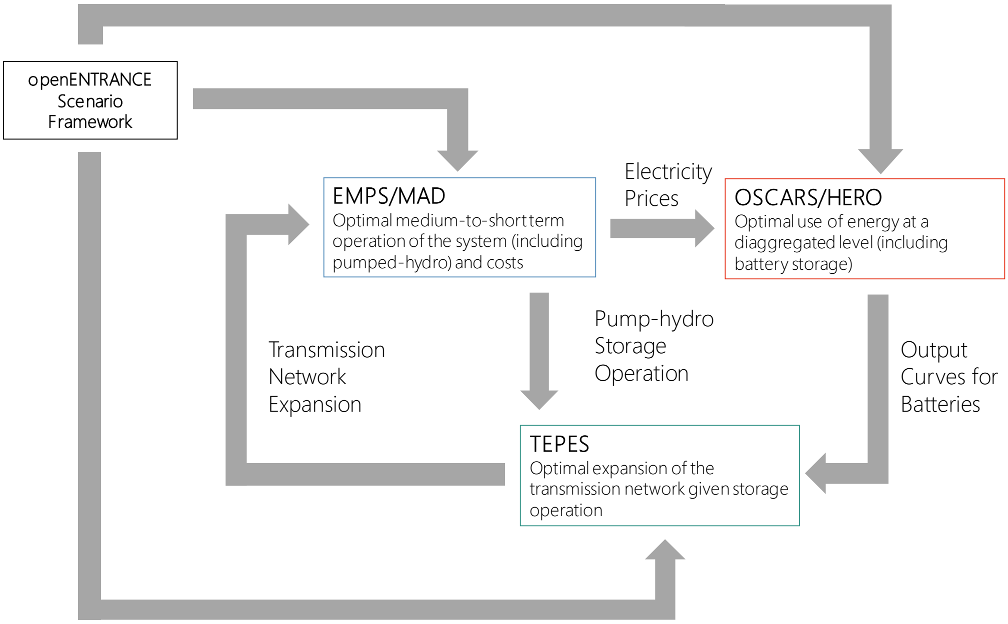
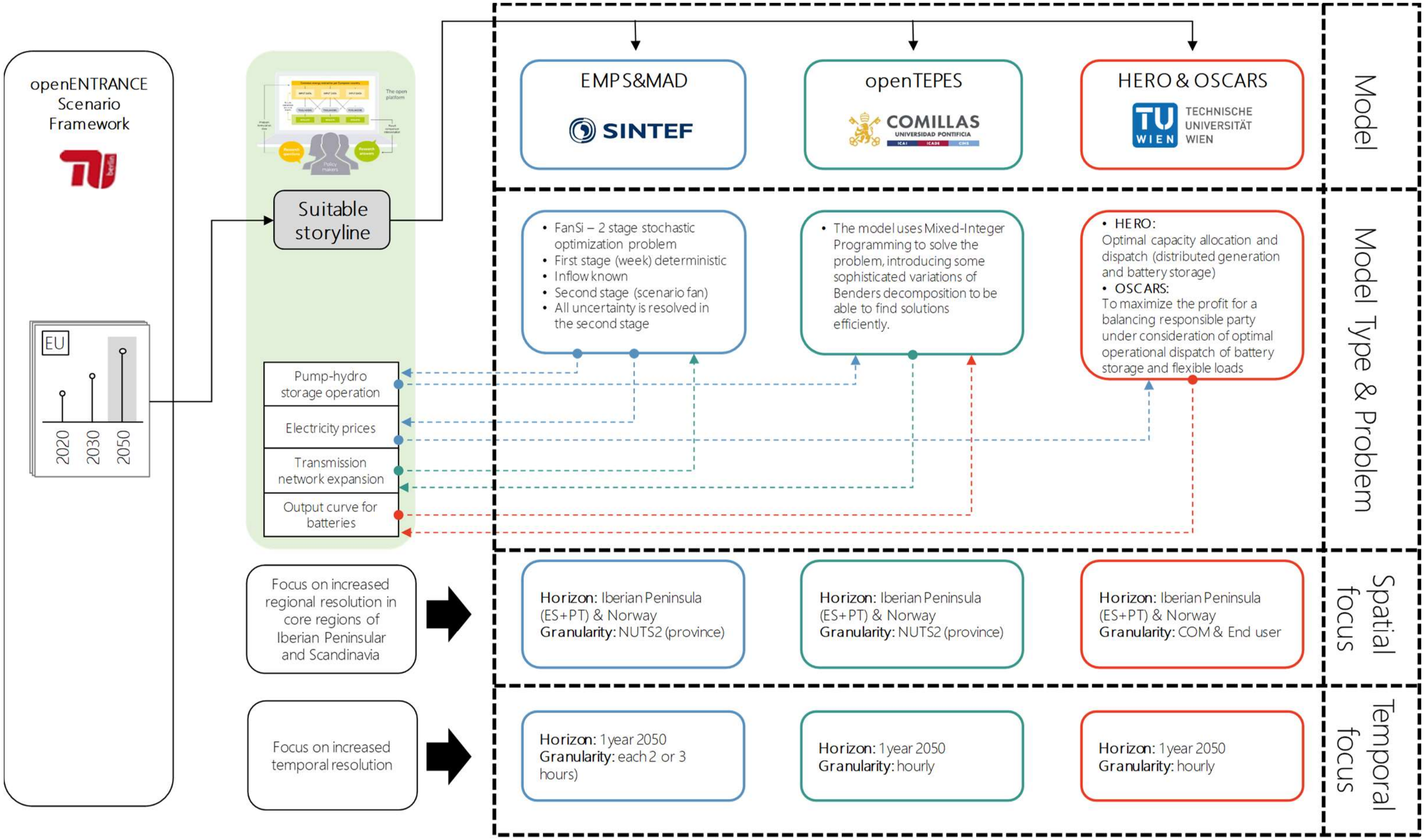


Figure 19: CS3 high-level Workflow

Figure 20: A Schematic overview of the case study 3 (methodology and model linkage).



3.3.7 General list of data

The following data lists illustrate key data sets needed to analyse the case study and its source.

Data from openENTRANCE scenarios (for the chosen scenario)

- Installed capacities per country per technology in 2050
- Energy demand per country per use in 2050
- Net electricity production from all sources of solar energy (e.g., solar PV and concentrating solar power)

Data coming from modelling teams own databases.

- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Other generation profiles (biomass for example)
- Electricity Demand profiles correlated to temperature time series
- Power technologies with their financial and technical parameters (Generation, Transmission & Distribution)
- Storage technologies
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Demand response technologies and potentials
- Temperature

Data produced during the case study exercise: mainly outputs of models

- Transmission grid (capacities between nodes)
- Generation profiles for wind, PV, hydro correlated to meteorological time series
- Fuel prices and CO2 emission price (or budget)
- Level of deployment of storage, which will consider several situations for the upscaling of hydro pumping and batteries.
- Operating strategy associated to the agent in charge of the operation of the batteries.
- A tactical transmission expansion plan for the regions focused.
- Different operating strategies will be translated into output curves (e.g. charging/discharging patterns and changing load profiles over time) that describe the use of storage.

3.3.8 Data workflow

To illustrate the details of the workflow in a general and specific way, we use the example in Figure 21. Facts that are illustrated in the figure:

- The openENTRANCE database provides scenario information.
- There are three models that receive information from the database and outside the database
- There are tools to convert the data format that comes from each model to Common Data Format of the database and vice versa.
- Dashed lines represent the flow of information

In short, the dataPacks considered are:

- Whose content comes from openENTRANCE scenarios (**Pack1**)
- Whose content comes from model's own database
- Whose content comes from models' output (**Pack2**, **Pack3**, **Pack4** and **Pack5**) and is used as input for other models

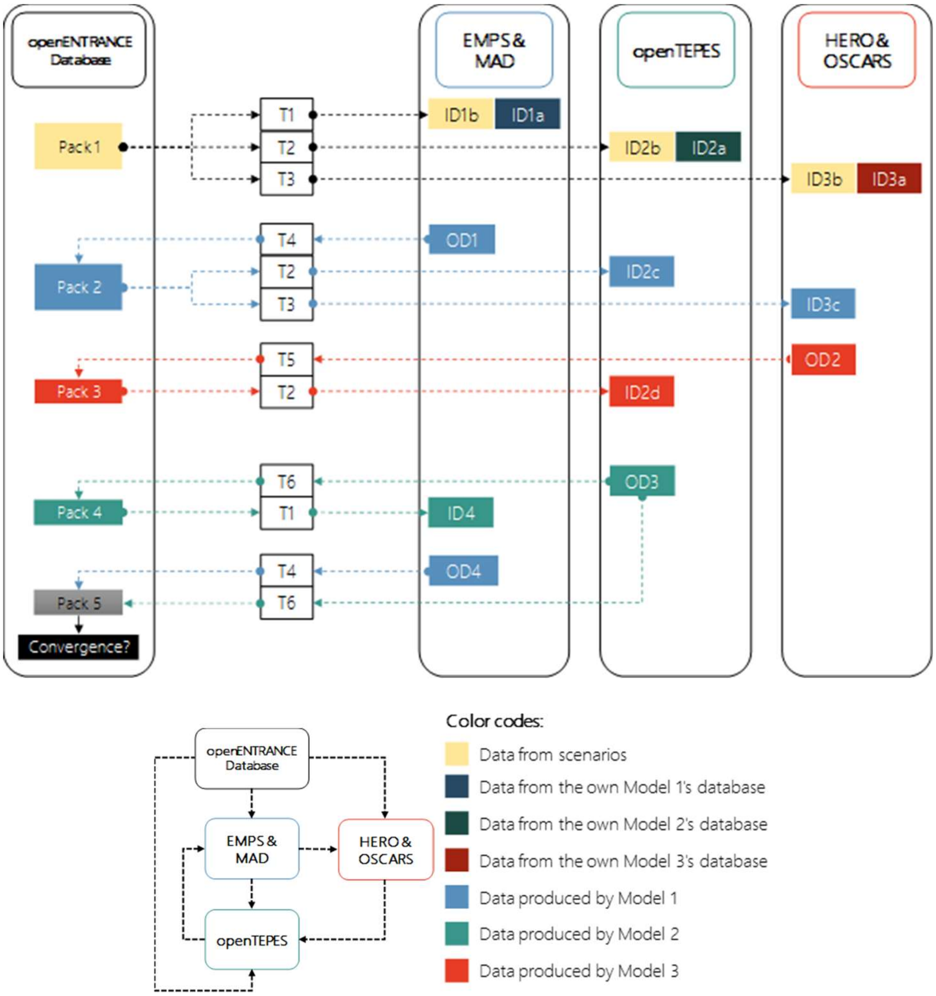


Figure 21: Data workflow

The data backs and features from the figure above are detailed as follows:

dataPack	Data flow	Content
Pack 1	Input data from Scenarios, common between models	Fuels and CO2 prices Technology operation costs

		Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data exchanged between EMPS&MAD, openTEPES and HERO&OSCARS (from EMPS&MAD Output to openTEPES and HERO&OSCARS' input)	Generation production for wind, solar PV, hydro correlated to meteorological time series Other generation production (biomass for example) Water values Scheduled use of reservoirs Electricity price
Pack 3	Data exchanged between openTEPES and HERO&OSCARS (from HERO&OSCARS Output to openTEPES input)	Electricity Demand profiles correlated to temperature time series (including electric vehicle profile) Output curve for batteries Behaviour profiles of electric vehicles
Pack 4	Data exchanged between EMPS&MAD and openTEPES (from openTEPES output to EMPS&MAD input)	Transmission expansion plan (capacities between “nodes”) Generation production for wind, solar PV, hydro correlated to meteorological time series Other generation production (biomass for example) Transmission Load Factors (TLF)
Pack 5	Output data from EMPS&MAD and openTEPES	Use of each technology (hourly and aggregated) per node Costs of transmission expansion plan Energy not supplied Marginal costs Electricity prices per node

List of Datasets (using the models own formats):

ID1a	**Input dataset** “part a” **that comes from the own** EMPS&MAD**’s database, *i.e. Reservoir topology***
ID1b	Input dataset **“part b”** that comes from the openENTRANCE database to EMPS&MAD, *i.e. energy resources, etc.*
ID2a	Input dataset **“part a”** that comes from the own **openTEPES**’s database, *i.e. Investment costs, network topology*
ID2b	Input dataset **“part b”** that comes from the openENTRANCE database to **openTEPES**, *i.e. Demand, etc.*
ID3a	Input dataset **“part a”** that comes from the own **HERO&OSCARS**’s database, *i.e. Battery storage capacities*
ID3b	Input dataset **“part a”** that comes from the openENTRANCE database to **HERO&OSCARS**, *i.e. Demand, capacities, etc.*
OD1	Output dataset from **EMPS&MAD** to openENTRANCE database, *i.e. Electricity prices and storage hydro operation*
ID2c	Input dataset **“part c”** that comes from the openENTRANCE database to **openTEPES**, *i.e. storage hydro operation*

ID3c	Input dataset **"part c"** that comes from the openENTRANCE database to **HERO&OSCARS**, *i.e. Electricity prices*
OD2	Output dataset from **HERO&OSCARS** to openENTRANCE database, *i.e. Output curves for batteries, power production*
ID2d	Input dataset **"part d"** that comes from the openENTRANCE database to **openTEPES**, *i.e. Output curves for batteries*
OD3	Output dataset from **openTEPES** to openENTRANCE database, *i.e. Transmission network expansion*
ID4	Input dataset that comes from the openENTRANCE database to **EMPS&MAD**, *i.e. Aggregated power network*
OD4	Output dataset from **EMPS&MAD** to openENTRANCE database, *i.e. Power production*

3.3.9 Data-exchange tools

T1 (OE- E&M)	Set of tools or methods to convert data from the **Common data format** to **EMPS&MAD format**
T2 (OE-oT)	Set of tools or methods to convert data from the **Common data format** to **openTEPES format**
T3 (OE-H&O)	**Set of tools or methods to convert data from the** Common data format **to** HERO&OSCARS format
T4 (E&M -OE)	Set of tools or methods to convert data from **EMPS&MAD output format** to **Common data format**
T5 (H&O-OE)	**Set of tools or methods to convert data from** HERO&OSCARS output format **to** Common data format
T6 (oT 2-OE)	Set of tools or methods to convert data from **openTEPES output format** to **Common data format**

3.3.10 Execution order

<u>Extraction of data from openENTRANCE Database:</u> First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T1**, **T2** and **T3** into **EMPS&MAD**, **openTEPES** and **HERO&OSCARS** data formats **ID1b**, **ID2b** and **ID3b**.

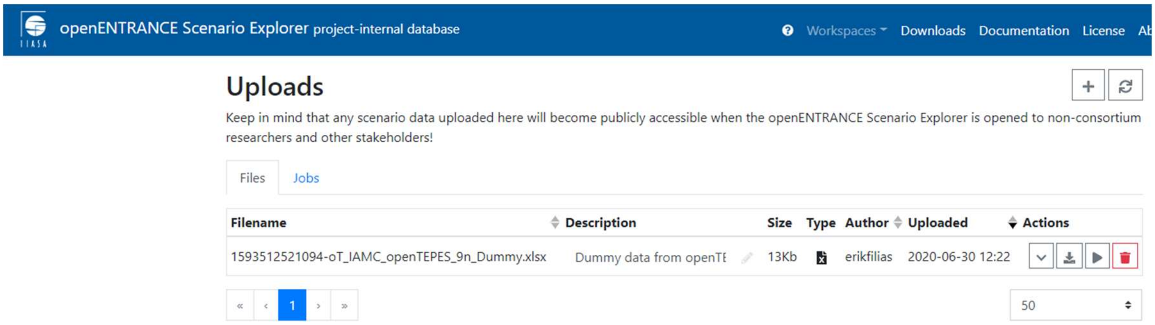
1. **<u>Building Model 1 Input dataset and running EMPS&MAD:</u>** The EMPS&MAD's dataset is built out of EMPS&MAD own data (**ID1a**) and openENTRANCE Scenario data (**ID1b**). EMPS&MAD is executed and produces output**s. OD1** is the part of the outputs that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD1** is converted to the **Common data format** using **T4**, which produces **Pack2.**
2. **<u>Exchanging between EMPS&MAD and openTEPES</u>**: Data from **Pack2** (produced by **EMPS&MAD**) are downloaded and converted to **openTEPES** format using **T2** => **ID2c**.

3. **Exchanging between EMPS&MAD and HERO&OSCARS**: Data from **Pack2** (produced by **EMPS&MAD**) are downloaded and converted to **HERO&OSCARS** format using **T3** => **ID3c**.
4. **Building HERO&OSCARS Input dataset and running HERO&OSCARS:** The HERO&OSCARS's dataset is built out of HERO&OSCARS own data (**ID3a**) and openENTRANCE database (**ID3b and ID3c**). **HERO&OSCARS** is executed and produces outputs. **OD2** is the part of the outputs that can be shared, while other part of the results will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD2** is converted to the **Common data format** using **T5**, which produces **Pack3.**
5. **Exchanging between HERO&OSCARS and openTEPES**: Data from **Pack3** (produced by **openTEPES**) are downloaded and converted to **openTEPES** format using **T2** => **ID2d**.
6. **Building openTEPES Input dataset and running openTEPES:** The openTEPES's dataset is built out of openTEPES own data (**ID2a**) and openENTRANCE database (**ID2b, ID2c and ID2d**). openTEPES is executed and produces outputs. **OD3** is the part of the outputs that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD3** is converted to the **Common data format** using **T6**, which produces **Pack4.**
7. **Updating EMPS&MAD dataset and running EMPS&MAD**: **ID4** data from **openTEPES** is downloaded from **Pack4** and used in order to update the **EMPS&MAD** dataset: **ID4** is created by **T1.** EMPS&MAD are ran again, which produces the new output **OD4.**
8. **Building Pack5:** **OD3** is converted to the **Common data format** using **T6.** And, **OD4** is converted to the **Common data format** using **T4.** Both data (**OD3 and OD4**) produce **Pack5.**
9. Expert analysis of outputs will determine whether a new cycle is necessary that depends of the case study.

3.3.11 Implementation in the openENTRANCE scenario Explorer (screenshot)

This section contains a first exchange of results between the case study models and the Scenario Explorer.

A file with test data of the case study provided by openTEPES v1.6.32 was uploaded to the openENTRANCE Scenario Explorer.



Uploads

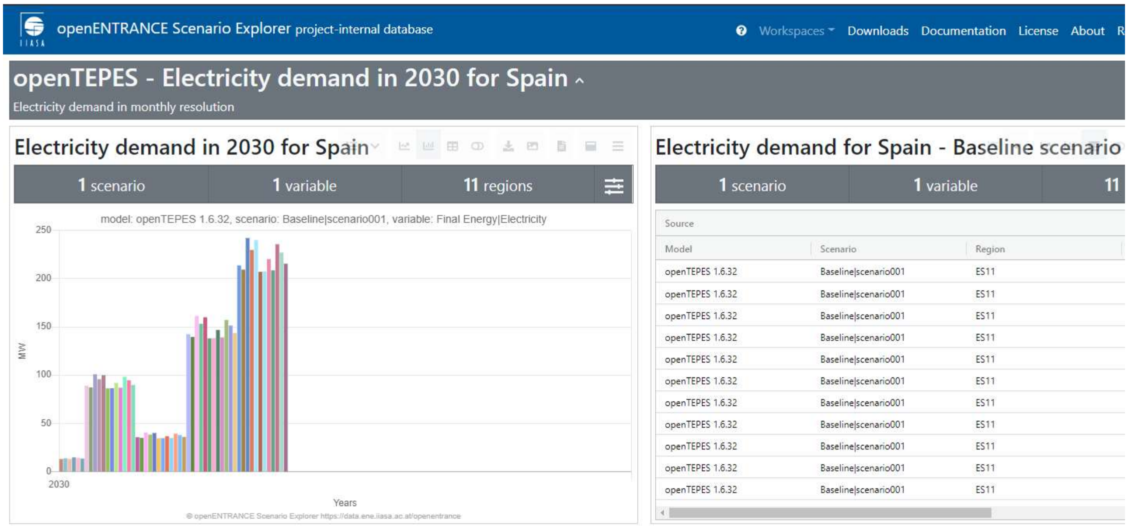
Keep in mind that any scenario data uploaded here will become publicly accessible when the openENTRANCE Scenario Explorer is opened to non-consortium researchers and other stakeholders!

Filename	Description	Size	Type	Author	Uploaded	Actions
1593512521094-oT_IAMC_openTEPES_9n_Dummy.xlsx	Dummy data from openTE	13Kb		erikfilias	2020-06-30 12:22	

Figure 22: Screenshot of uploading openTEPES data to openENTRANCE Scenario Explorer

Before uploading it, the file was validated to make sure the format of data in it complies with the openENTRANCE exchange data format and is compatible with the nomenclature agreed that far.

As a result of this uploading, the workspace in the figure below was generated to graphically represent the corresponding data and be able to share these data among models. The set of data uploaded corresponds to the electricity demand in each region (NUT2) in Spain and each month in the year 2030.



openTEPES - Electricity demand in 2030 for Spain

Electricity demand in monthly resolution

Electricity demand in 2030 for Spain

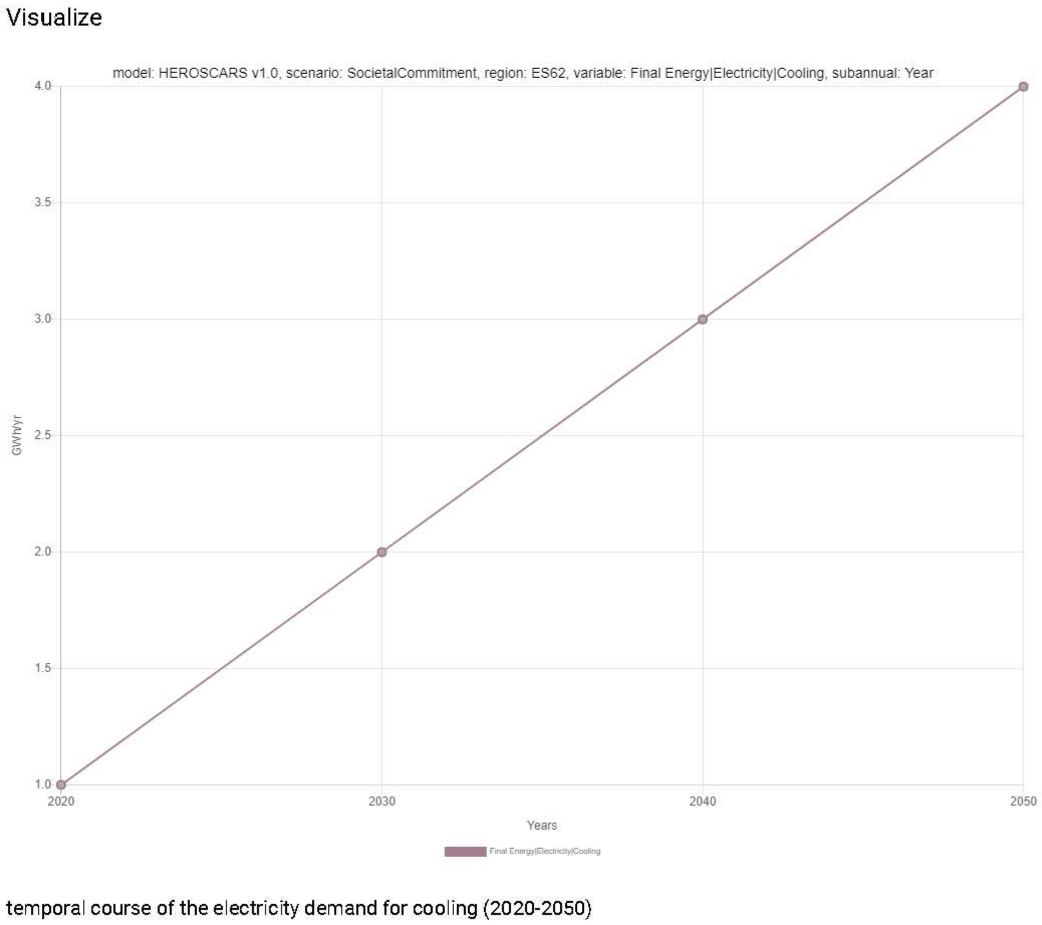
Electricity demand for Spain - Baseline scenario

Source

Model	Scenario	Region
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11
openTEPES 1.6.32	Baseline|scenario001	ES11

Figure 23: Screenshot of the workspace generated from openTEPES data at the openENTRANCE Scenario Explorer

Additionally, also data on the use of electricity (electricity demand) for cooling in the Societal Commitment scenario was uploaded onto the Scenario Explorer. These is data used by the model HERO/OSCARS. As aforementioned, before being able to upload these data, their compliance with the commonly agreed format has been checked.



Visualize

temporal course of the electricity demand for cooling (2020-2050)

Figure 24. Electricity demand for cooling (2020-2050) used in HERO/OSCARS

3.4 Case Study 4- Need for cross-sectoral flexibility

3.4.1 Case study objective, challenges and beyond the state of the art

In this case study, a simulation over the whole pan-European energy system will be run with the models SCOPE SD (FhG IEE) and Plan4EU (EDF). The main objective is to simulate the expansion and operation of the pan-European power system with a particular focus on transport sector technologies, i.e. (hybrid) electric vehicles, hybrid electric overhead-line highway trucks, while integrating all relevant flexibility assets, network costs and constraints on a local and decentralized level.

It is the underlying assumption that low-carbon energy systems in Europe need to be based on cross-sectoral integration to meet climate protection goals. Cost-efficient coupling of the power with heat and transport sectors implies additional demands for renewable electricity but integrating technologies at the interfaces between those sectors may also provide a valuable source of flexibility. As multiple studies have been carried out on a one-node-per-country level, little is known about how the integration of cross-sectoral technologies plays out in the local but interconnected domain. By addressing these aspects with the SCOPE SD and Plan4EU models, the involved flexibility considerations also focus on the consumer behaviour perspective through investigating a different willingness to provide flexibility for electric vehicle owners.

SCOPE SD model simulations will include a high sectoral and temporal resolution and a medium spatial (country level). The Plan4EU will focus on the electricity sector only but with a high temporal and spatial resolution (regions), also including representations of aggregated distribution constraints. SCOPE SD and Plan4EU will be linked together as to run Plan4EU simulations with inputs out of SCOPE SD.

Challenge

By analysing the impact of a high electric vehicle penetration on the low-carbon electrical systems in Europe, the case study addresses an important challenge of increasing sectoral integration that can be characterised as follows:

- Comprehensive analysis of the impact on the electrical system of a high penetration of electric vehicles (allowing or not flexible charging) under the consideration of local/regional feasibility and dynamical constraints
- Explicit representation of vital cross-sectoral links and flexibility potential for low-carbon energy pathways, particularly hybrid technology configurations for industry, heat, and transport sector demand applications.
- Extending the one-node-per-country focus to better spatial granularity required to evaluate how flexibility plays out in the more detailed regional domain.
- Accounting for willingness to provide flexibility with a sufficient number of transport sector option instances to capture full technology range (niche applications).
- Concurrent analysis of hourly time-series data for multiple signals from the power sector (e.g. wind, solar PV, electricity demand, hydro inflow), building and industry heat sector (e.g. heat demand, heat pump COP profiles), as well as the transport sector (e.g. transport demands, potential charging power, battery SOC limits).
- Providing regional data for German and French market areas by defining consistent market areas for power grid and other sector coupling technologies.

3.4.2 Detailed methodology of the case study: modus operandi

First, pan-European reference scenarios will be implemented from WP 3 in both model environments to determine further assumptions necessary for the detailed case study. Simulations will then be performed with SCOPE SD, including sensitivities regarding the share of flexible charging in all or selected European countries (i.e. uncontrolled versus system-friendly charging behaviour).

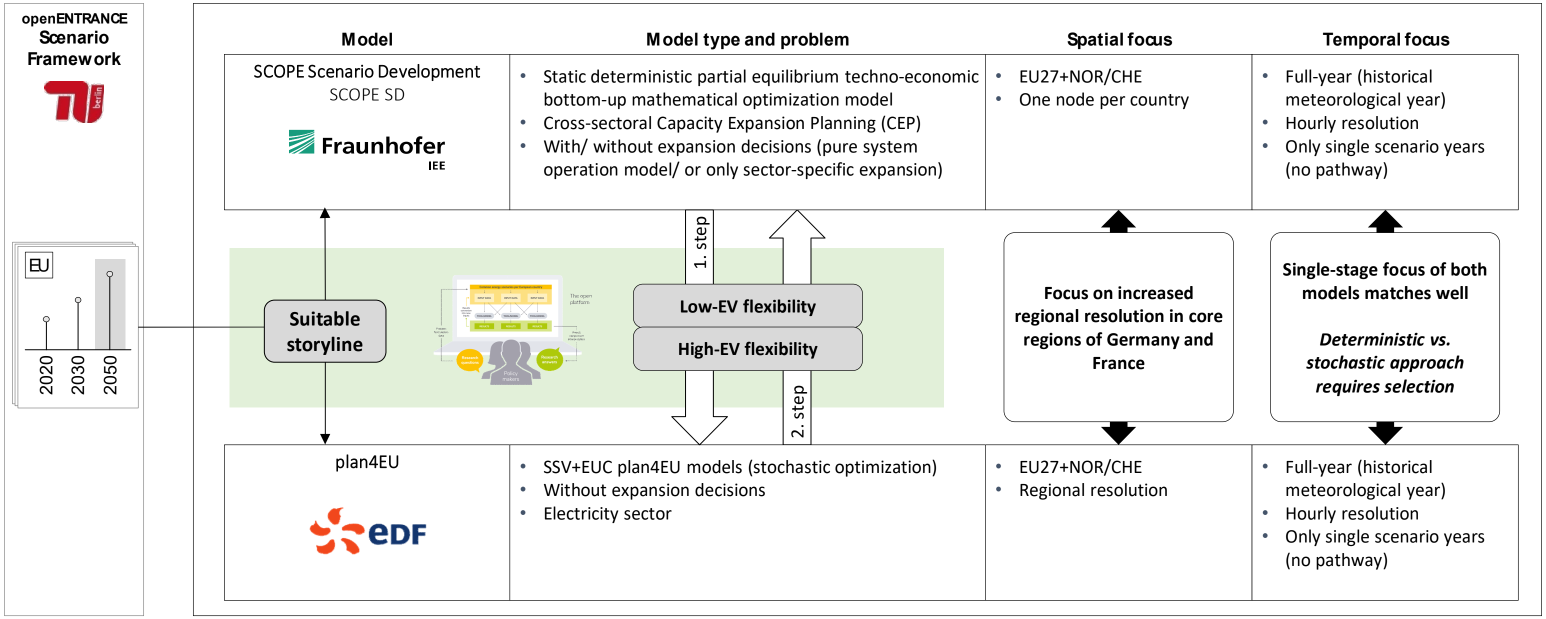
Then, the flexibility information from SCOPE SD will be integrated into the plan4EU modelling framework to run more detailed simulations regarding the electricity sector.

The primary approach is to run the SCOPE SD model in a first step focussing on the national level, and use these aggregate results as input for the Plan4EU model. In a second step, the Plan4EU model processes and disaggregates the country-specific input data to then perform the electricity market simulations in the more detailed regional domain.

A potential extension of this modelling chain is to already include a more detailed regional focus of Germany and France in the SCOPE SD model (based on the initial Plan4EU results). By increasing the spatial resolution in terms of multiple bidding zones per country, some limitations regarding internal transmission grid effects could be alleviated. A more detailed spatial resolution allows for a more accurate aggregation (i.e. not to the national but only regional level) of the transport sector flexibility parameters. The Plan4EU model can use the new results from the SCOPE SD model with better assumptions on local potentials for flexibility in a second run. As a consequence, the two versions of running the models can be compared to provide insights into the impact of decentralised flexibility of electric vehicles on the grid and expansion planning.

Further aspects to investigate in optional analyses include a refined modelling approach of the power flow in the Plan4EU model, i.e. using a DC power flow approximation instead of a transport model (NTC). Another aspect focuses on the capacity limits between distribution and transmission network, which is particularly relevant since large shares of renewable power generation as well as electric vehicle charging is connected to the distribution grid level.

The following figure presents a schematic overview of the case study methodology and linkage of modelling frameworks.



Model	Model type and problem	Spatial focus	Temporal focus
SCOPE Scenario Development SCOPE SD Fraunhofer IEE	• Static deterministic partial equilibrium techno-economic bottom-up mathematical optimization model • Cross-sectoral Capacity Expansion Planning (CEP) • With/ without expansion decisions (pure system operation model/ or only sector-specific expansion)	• EU27+NOR/CHE • One node per country	• Full-year (historical meteorological year) • Hourly resolution • Only single scenario years (no pathway)
plan4EU eDF	• SSV+EUC plan4EU models (stochastic optimization) • Without expansion decisions • Electricity sector	• EU27+NOR/CHE • Regional resolution	• Full-year (historical meteorological year) • Hourly resolution • Only single scenario years (no pathway)

Figure 25 : Schematic overview of the case study methodology and model linkage.

3.4.3 Expected results and limitations

Expected results cover the flexibility and integration potential of transport sector technologies in the country domain and the more constrained regional domain. Based on a predefined storyline, the following scenario configuration is to be investigated:

- European scenario with high share of flexible charging behaviour across Europe / Germany / France
- European scenario with low share of flexible charging behaviour across Europe / Germany / France

General results

- Comparison of flexibility and integration potential of transport sector technologies at the country level.
- Can transport sector technology integration potential in the country domain be realised in the more constrained regional domain of Europe?
- Cross-validation of the scenario results of the WP 3, especially those with high levels of decarbonisation and cross-sectoral integration.

Specific results for the SCOPE SD modelling framework

- Possible EV flexibility variants, including with different willingness to provide flexible charging (non-flexible, flexible, V2G).
- Investment and system operation decisions in all relevant energy sectors.
- Other flexibility decisions and backup utilisation.
- Price impacts (wholesale electricity, potentially carbon price).
- Core region impacts and repercussions in Germany and France.
- Optimal electricity generation capacity mix.
- Optimal heat generation capacity mix.
- Optimal transport sector capacity mix.
- Electricity demand (MWh for 2050 per country).
- Flexibility potentials for electric road transport technologies

Specific results for the Plan4EU modelling framework

- Indicators: Plan4EU will provide several indicators allowing to evaluate the value of flexible charging for the electrical system in terms of operation costs; renewable curtailment level; pollutant/CO2 emissions; network congestions; dual variables (that can be interpreted as prices) related to demand constraints or capacity limits of power lines.
- Strategic decisions under uncertainties: one interesting aspect of Plan4EU is the ability to take into account mid-term uncertainties (e.g. variable renewable production, inflows, demand) when designing strategic decisions related large scale storage (e.g. water reservoirs). This seems to be a crucial point since solar and wind production may

significantly vary from one year to another which requires to carefully manage large scale storage w.r.t. that uncertainty.

- Impact of mid-term uncertainties: beyond the strategic decision issue, it is also interesting to investigate the variability of the computed indicators by simulating the operation decisions on several scenario of uncertainties.
- Reference run with non-/low-flexible EV.
- Impact of optimising EV-flexibility.
- Details of sensitivities need to be further defined during the case study phase.

Limitations

- Modelling the power system on a single year operation (e.g. 2050 horizon).
- Uncertainty consideration (SCOPE SD model), particularly long-term uncertainty.
- SCOPE SD does not feature intra-zonal grid congestions as it is only a market-based capacity expansion planning model.
- Modelling of hydro generation is aggregated (equivalent hydropower valleys in SCOPE SD; one lake by country/region, no hydro valleys in Plan4EU).
- Modelling of transmission network is simplified (clustering).
- Modelling of distribution network is limited to the reinforcement's costs and global constraints at each node of the transmission network (maximum amount of power injected into the distribution network at each hour).
- Aggregation of heterogeneous vehicles storage into a single representative storage per node (Plan4EU).
- Short-term uncertainties are not taken into account (everything is supposed to be known within a day): arrival and departure of electric vehicles to the parking station are not taken into account, variable renewable generation are not taken into account (Plan4EU).

3.4.4 Set of models

Table 7. Overview of models involved in the case study methodology

MODEL	LEAD PARTNER	MAIN OBJECTIVE
SCOPE SD (Scenario Development configuration)	FhG IEE	To optimise least-cost energy system configurations and operations
Plan4EU	EDF	To study the effects of macroeconomic policies on the EU economy.

Table 8 presents a format for the summary of the model characteristics and requirements.

Table 8. Summary of the modelling horizons, granularity and scope

	Geography		Time		Technological scope
	Horizon	**Granularity**	**Horizon**	**Granularity**	
SCOPE SD	EU27 – MT – CY + NO + CH + UK	One node per country (national bidding zones) Optional: eHighWay2050 clusters for Germany and France	1 year (e.g. 2050)	Hourly (full consecutive year)	• On-/Offshore Wind • Solar PV • Hydropower • Thermal power plants • Cogeneration • Energy storage • Power-to-heat • Power-to-gas • Cooling Processes • BEV • (Hybrid) Boiler • Heat pumps • Solar thermal • PHEV/REEV • Electric hybrid trucks • Geothermal
Plan4EU	EU27 – MT – CY + AL + BA + CH + ME + MK + NO + RS + UK	France and Germany: ehighway2050 clusters (defined in Nomenclature) Aggregated regions: Scandinavia, Balkans, Baltics The rest: countries	1 year (e.g. 2050)	Hourly (weekly for water values)	• Only electricity transmission, generation, storage and uses (with focus on flexibilities) , from the above scope

By linking the SCOPE SD (Fraunhofer IEE) and plan4EU (EDF) modelling and optimisation frameworks, the case study combines a proprietary with an open-source modelling framework via the openENTRANCE database.

SCOPE SD modelling framework

Model type and problem

The modelling and optimisation framework SCOPE SD develops a long-term low-carbon energy system scenario for Europe. By minimising the generation, storage, and cross-sectoral consumer technology investment and system operation cost, this large-scale linear programming approach features representations for the traditional power system as well as all relevant bi- and multivalent technology combinations at the sectoral interfaces with the heat, industry, and transport sectors.

The modelling and optimisation framework type and problem can be further characterised by the following aspects:

- SCOPE SD determines cost-optimised target scenarios of future energy systems with energy and emission targets while capturing a wide range of technology combinations.
- The methodological approach corresponds to a static deterministic partial equilibrium techno-economic bottom-up mathematical optimisation model (large-scale LP problem instances typically feature more than 40 million constraints and more than 40 million decision variables requiring high-performance computing nodes).
- “Static planning”, i.e. only single scenario years and no pathway (“dynamic planning”)
- Cross-sectoral Capacity Expansion Planning (CEP), i.e. traditional generation expansion planning plus capacity expansion planning decisions for energy storage, as well as heat (building and industry), and transport sector applications.
- With/ without expansion decisions (pure system operation model/ or only sector-specific expansion).
- Modelling framework suitable for short- to medium-term “brown-field” and long-term “green-field” analyses.

Input data

Note that full-scale problem instances, e.g. for the pan-European energy sectors, require a substantial amount of structural and time-series input data. The main data requirements for this case study are complete scenarios for:

- Transmission grid (capacities between nodes)
- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Generation profiles for wind, solar PV, hydro correlated to meteorological time series
- Other generation profiles (biomass for example)
- Electricity Demand profiles correlated to temperature time series (including electric vehicle profile)
- Power technologies with their financial and technical parameters
- Storage technologies
- Emission factors
- Fuel prices and CO2 emission price (or budget)
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Demand response technologies and potentials

Output data

- Optimised power generation and storage mix
- Heat generation mix
- Transport mix
- Energy units utilization and operations along with installed capacity
- CO2 emission price

Schematic model overview

Figure 26 presents a schematic overview of the SCOPE SD modelling and optimisation framework, including high-level information on its in- and output data, as well as the considered markets and technology options.

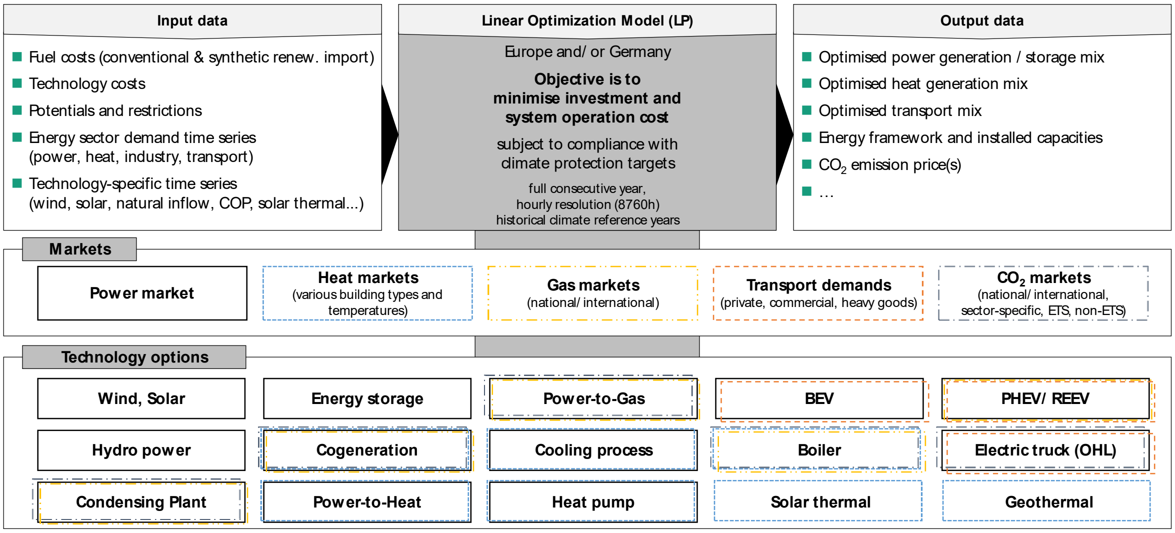


Figure 26: Schematic overview of the SCOPE SD modelling and optimisation framework developed at Fraunhofer IEE.

Plan4EU modelling framework

Model type and problem

Case study 4 will make use of the scenario valuation layer of the Plan4EU modelling and optimization framework, which evaluates the investment decisions from the capacity expansion model by means of modelling the operation of the existing assets in the energy system. More specifically, this layer contains two distinct models: the first model is referred to as the seasonal storage valuation (SSV) model and the second model is referred to as the European unit commitment (EUC) model. Both models are further described below.

Seasonal storage valuation model (SSV)

The objective of the seasonal storage valuation model is to provide an accurate account of "the value" that seasonal storage can bring to the system. Indeed, such seasonal storage (e.g., cascaded reservoir systems) can be used to store energy over large spans of time and use this "stored" energy when most needed. The actual use may in particular depend on adverse climatic situations (intense cold), but the ability to store the energy may in turn also depends on climatic conditions (e.g. draught). It is therefore clear that such a vision of value should be transferred in an appropriate way to shorter time span tools, such as the EUC model. In turn computing an accurate value intrinsically depends on the value of substitution, and thus ultimately on the EUC tool as well.

European Unit Commitment (EUC)

The EUC model computes an optimal (or near optimal) schedule for all the system assets on a typical period of one year, with a typical granularity of one hour in order to satisfy demand and ancillary services at the lowest cost. It ensures that the given system is « feasible » in the sense that at each hour of the year, including peak hours, it is able to fulfil the following constraints

- power demand supply;
- ancillary services supply;
- minimal inertia in the system;
- maximum transmission and distribution capacities between clusters;
- technical constraints of all assets.

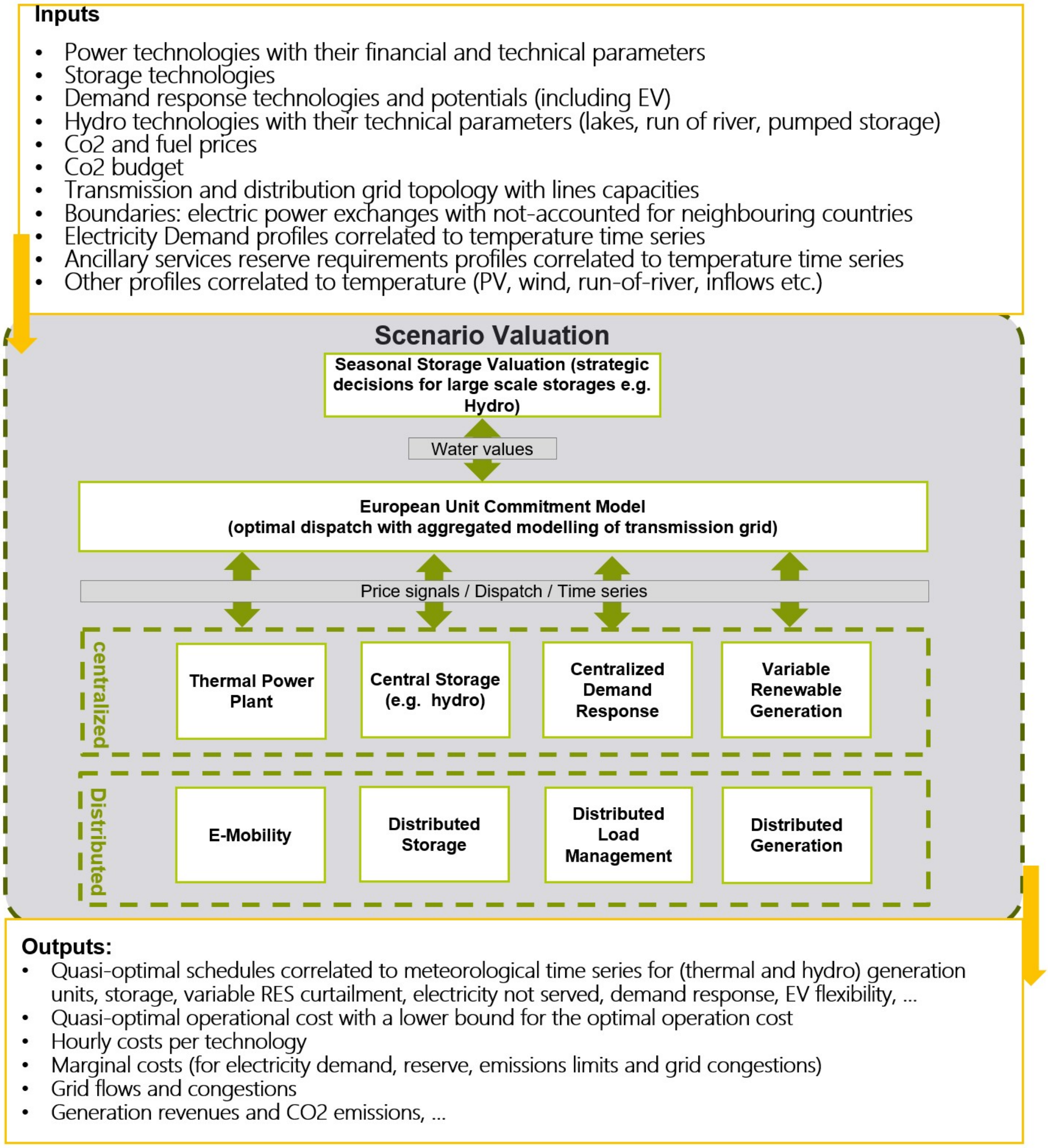
Input data

Required input data mostly corresponds to the data described for the SCOPE SD model. Additional data requirements can be characterised by:

- At each node of the network, a reference load profile corresponding to the standard aggregate consumption of electric vehicles connected to that node with a time step of one hour for some typical days (e.g. working day or week-end in spring/summer/winter).
- Flexibility is specified by a reference load profile and by an upper and lower deviation allowed around that reference load profile. As a load In addition to that deviation limit from the reference profile the flexible load profile should also corresponds to the same energy consumption as the reference profile on the given day. The reference profile should also be specified with a time step of one hour for some typical days (e.g. working day or weekend in spring/summer/winter).

Output data

- Quasi-optimal schedules correlated to meteorological time series for (thermal and hydro) generation units, storage, variable RES curtailment, electricity not served, demand response, EV flexibility, and etc.
- Quasi-optimal operational cost with a lower bound for the optimal operation cost
- Hourly costs per technology
- Marginal costs (for electricity demand, reserve, emissions limits and grid congestions)
- Grid congestions
- Generation revenues
- CO2 emissions, and others



Inputs

- Power technologies with their financial and technical parameters
- Storage technologies
- Demand response technologies and potentials (including EV)
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Co2 and fuel prices
- Co2 budget
- Transmission and distribution grid topology with lines capacities
- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Electricity Demand profiles correlated to temperature time series
- Ancillary services reserve requirements profiles correlated to temperature time series
- Other profiles correlated to temperature (PV, wind, run-of-river, inflows etc.)

Outputs:

- Quasi-optimal schedules correlated to meteorological time series for (thermal and hydro) generation units, storage, variable RES curtailment, electricity not served, demand response, EV flexibility, …
- Quasi-optimal operational cost with a lower bound for the optimal operation cost
- Hourly costs per technology
- Marginal costs (for electricity demand, reserve, emissions limits and grid congestions)
- Grid flows and congestions
- Generation revenues and CO2 emissions, …

Figure 27: Schematic overview of the Plan4EU modelling framework developed at EDF.

3.4.5 Workflow of the case study

CS4 will first implement the openENTRANCE scenarios into the models in order to run them and give qualitative answers to the possible impact of flexibility potentials for electric vehicle on the energy system. For the sake of simplicity, the workflow is presented here in the first case of application and a preview of the second possible step.

The diagram below presents a wide perspective of the workflow.

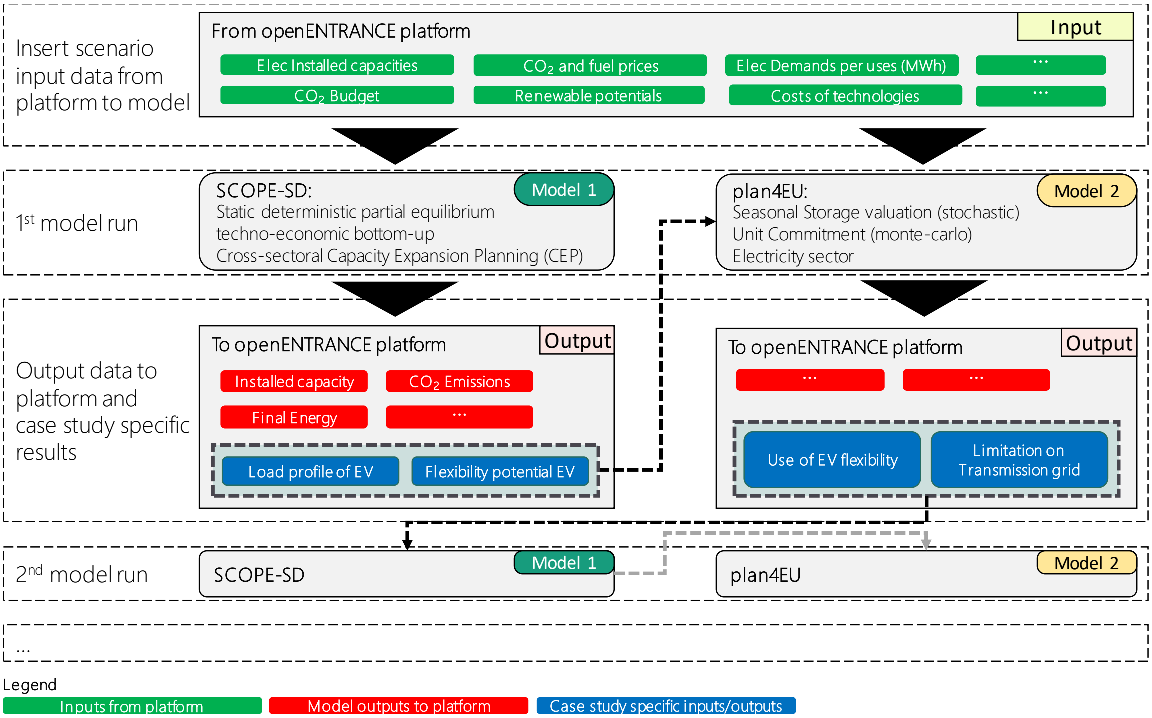


Figure 28: Schematic representation of the general workflow in case study 4

All data are following the openENTRANCE Data Format (see D4.2[25]).

3.4.6 General list of data

The following data lists illustrate key data sets needed to analyse the case study and its source.

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Installed capacities per country per technology in 2050
- Energy demand per country per use in 2050
- Net electricity production from all sources of solar energy (e.g., solar PV and concentrating solar power)
- Investments into electricity generation and supply (including electricity storage and transmission & distribution)

---

[25] Open Entrance deliverable 4.2: data exchange format and template

Data coming from modelling teams own databases

- Boundaries: electric power exchanges with not-accounted for neighbouring countries
- Other generation profiles (biomass for example)
- Electricity Demand profiles correlated to temperature time series (including electric vehicle profile)
- Power technologies with their financial and technical parameters
- Storage technologies
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Demand response technologies and potentials

Data produced during the case study exercise (mainly outputs of models)

This data will be exchanged between models as inputs for someone and output for others. As examples of it, we have:

- Transmission grid (capacities between nodes)
- Generation profiles for wind, solar PV, hydro correlated to meteorological time series
- Fuel prices and CO2 emission price (or budget)
- Reference load profile at each node, corresponding to the standard aggregate consumption of electric vehicles connected to that node with a time step of one hour for some typical days (e.g. working day or weekend in spring/summer/winter).
- Flexibility is specified by an upper and lower deviation allowed around the reference load profile that should also be specified with a time step of one hour for some typical days (e.g. working day or weekend in spring/summer/winter).

3.4.7 Data workflow

The specificities of the data exchanged among models are presented in this section and Figure 29. Facts that are illustrated in the figure:

- The openENTRANCE database provides scenario information.
- There are two models that receive information from the database and outside the database
- There are tools to convert the data format that comes from each model to Common Data Format of the database and vice versa.
- Dashed lines represent the flow of information

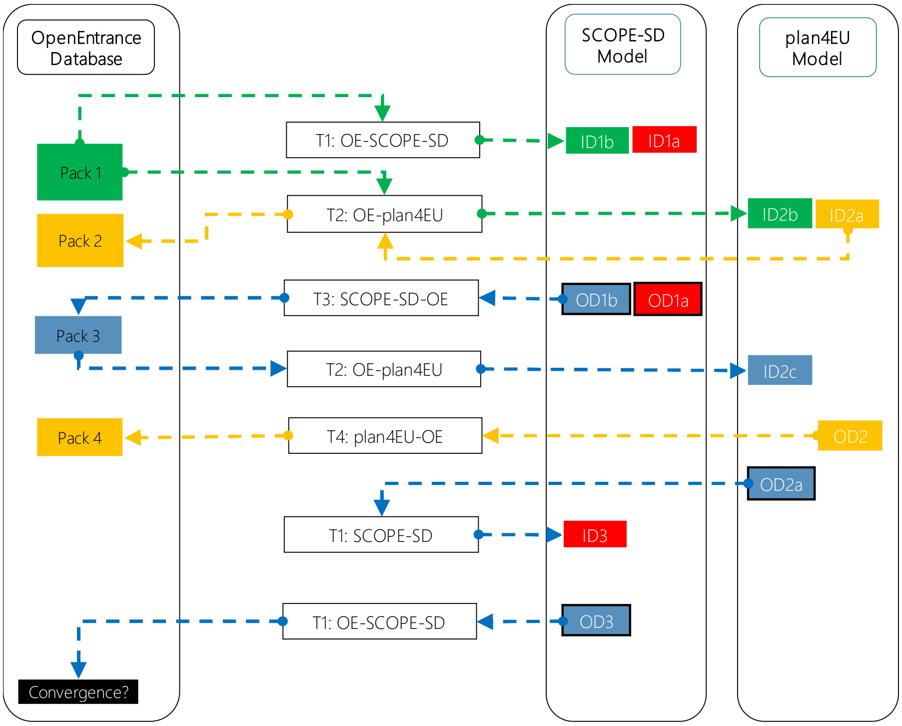


Figure 29: Other example with also data coming from model's databases

dataPack	Data flow	Content, as example:
Pack 1	Input data from Scenarios, common between models	Technology operation costs Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data exchanged between Model 1, Model 2 and Model 3 (from Model 1 Output to Model 2 and Model 3 input)	Generation profiles for wind, PV, hydro correlated to meteorological time series Other generation profiles (biomass for example) Electricity Demand profiles correlated to temperature time series (including electric vehicle profile) Power technologies with their financial and technical parameters Storage technologies
Pack 3	Data exchanged between Model 2 and Model 3 (from Model 3 Output to Model 2 input)	load profiles of electric vehicles nodes EV Flexibility (upper and lower deviation allowed around load profile)
Pack 4	Data exchanged between Model 1 and	Transmission grid (capacities between "nodes")

🟨	Model 2 (from Model 2 output to Model 1 input)	Boundaries: electric power exchanges with not-accounted for neighbouring countries

List of Datasets (using the models own formats):

ID1a	Input dataset **“part a”** that comes from the own **SCOPE-SD**’s database, *i.e. charging profiles of EV*
ID1b	Input dataset **“part b”** that comes from the openENTRANCE database to **SCOPE-SD**, *i.e. installed capacities, etc.*
ID2a	Input dataset **“part a”** that comes from the own **plan4EU**’s database, *i.e. network topology*
ID2b	Input dataset **“part b”** that comes from the openENTRANCE database to **plan4EU**, *i.e. demand, etc.*
ID3	Input dataset that comes from the **plan4EU**’s own database to **SCOPE-SD**’s, *i.e. network restrictions*
OD1a	Input dataset “**part a**” that comes from the own **SCOP-SD**’s database, *i.e. reservoir topology, flexibility potentials etc.*
OD1b	Output dataset from **SCOPE-SD** to openENTRANCE database, *i.e. CO2 emissions etc.*
ID2c	Input dataset **“part c”** that comes from the openENTRANCE database to **plan4EU**, *i.e. storage hydro operation*
OD2a	Output dataset from **plan4EU** to **SCOPE-SD**’s database, *i.e. network restrictions etc.*
OD2	Output dataset from **plan4EU** to openENTRANCE database, *i.e. transmission network expansion*
OD3	Output dataset from **SCOPE-SD** to openENTRANCE database, *i.e. time series of power production*

3.4.8 Data-exchange tools

T1 (OE-SCOPE-SD)	Set of tools or methods to convert data from the **Common data format** to **SCOPE-SD format**
T2 (OE-plan4EU)	Set of tools or methods to convert data from the **Common data format** to **plan4EU format**
T3 (SCOPE-SD-OE)	Set of tools or methods to convert data from **SCOPE-SD output format** to **Common data format**
T4 (paln4EU-OE)	Set of tools or methods to convert data from **plan4EU output format** to **Common data format**

3.4.9 Execution order

This section provides the stepwise plan to carry out the case study, specifying the data exchanged (with the relevant data-exchange tools if appropriate). An example is provided below:

1. **<u>Extraction of data from openENTRANCE Database:</u>** First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T** and **T2** into **SCOPE-SD** and **plan4EU** data formats **ID1b** and **ID2b**.

2. **<u>Building SCOPE-SD Input dataset and running it:</u>** The SCOPE-SD's dataset is built out of SCOPE-SD own data (**ID1a**) and openENTRANCE Scenario data (**ID1b**). SCOPE-SD is executed and produces outputs. **OD1** is the part of the output that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD1** is converted to the **Common data format** using **T2**, which produces **Pack2.**

3. **<u>Exchanging between SCOPE-SD and plan4EU</u>**: Data from **Pack3** (produced by **SCOPE-SD**) are downloaded and converted to **plan4EU** format using **T2** => **ID2c.**

4. **<u>Building plan4EU Input dataset and running it:</u>** The plan4EU's dataset is built out of it own data (**ID2a**) and openENTRANCE database (**ID2b, ID2c**). plan4EU is executed and produces outputs. **OD2a** is the part of the outputs that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD2** is converted to the **Common data format** using **T4**, which produces **Pack4.**

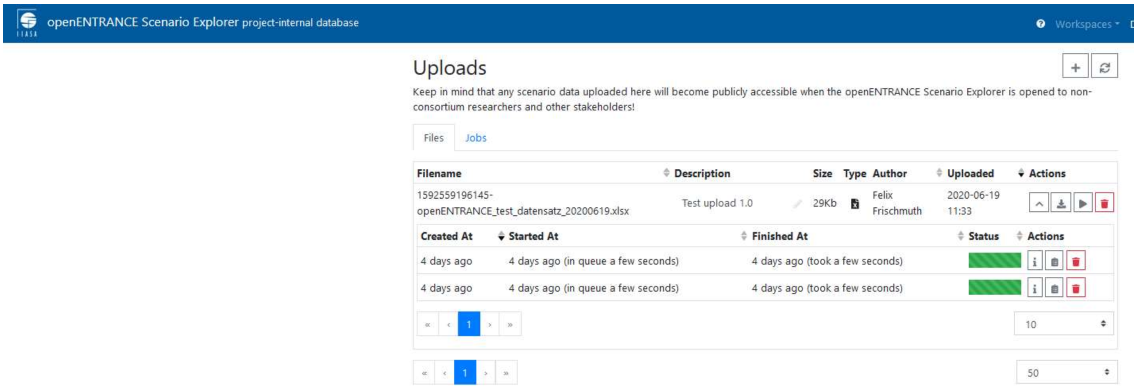
5. **<u>Updating SCOPE-SD dataset and running it</u>**: **ID3** data from **plan4EU** is downloaded from **Pack4** and used in order to update the **SCOPE-SD** dataset: **ID3** is created by **T1. SCOPE-SD** is running again, which produces the new output **OD3.**

6. **<u>Building Pack5:</u> OD3** is converted to the **Common data format** using

7. Expert analysis of outputs will determine whether a new cycle is necessary that depends of the case study.

3.4.10 Implementation in the openENTRANCE scenario Explorer (screenshot)

A file containing test data of the case study (model version SCOPE SD v1.0) was uploaded to the openENTRANCE Scenario Explorer:



Uploads

Keep in mind that any scenario data uploaded here will become publicly accessible when the openENTRANCE Scenario Explorer is opened to non-consortium researchers and other stakeholders!

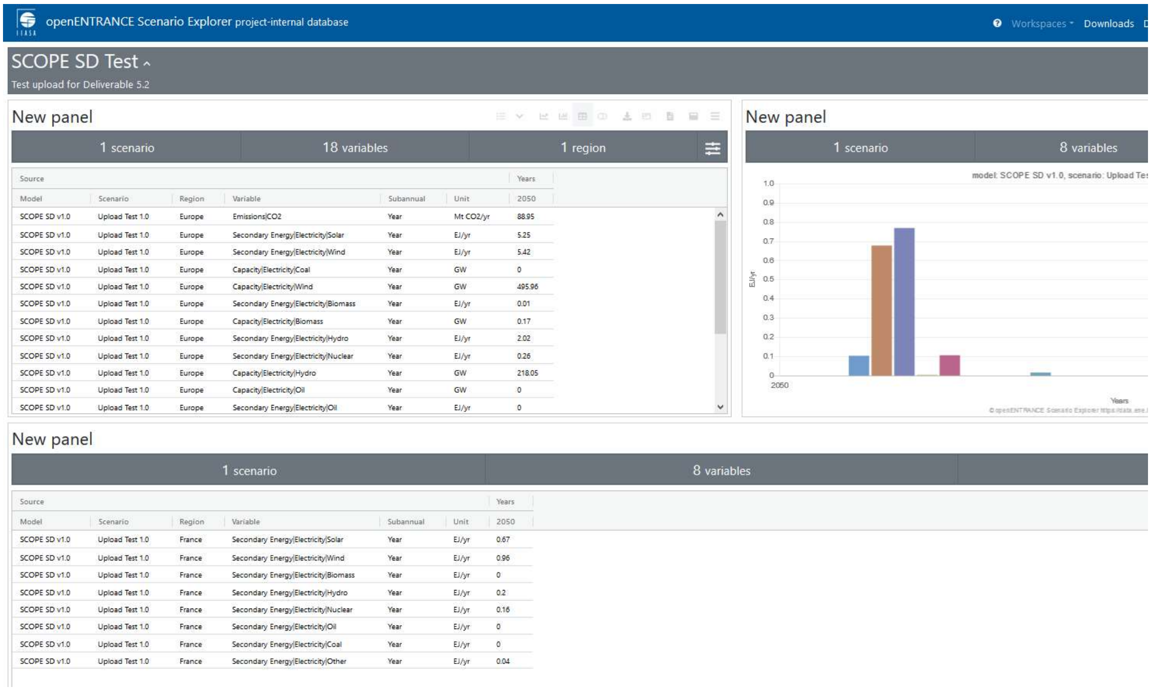
Filename	Description	Size	Type	Author	Uploaded	Actions
1592559196145-openENTRANCE_test_datensatz_20200619.xlsx	Test upload 1.0	29Kb		Felix Frischmuth	2020-06-19 11:33	

Created At	Started At	Finished At	Status	Actions
4 days ago	4 days ago (in queue a few seconds)	4 days ago (took a few seconds)	🟩	
4 days ago	4 days ago (in queue a few seconds)	4 days ago (took a few seconds)	🟩	

Figure 30: Test upload of SCOPE SD on the openENTRANCE Scenario Explorer

Before uploading, the file was thoroughly checked for compliance with the openENTRANCE nomenclature.

An exemplary workspace was created to visualize some of the data uploaded to the openENTRANCE Scenario Explorer.



Source						Years
Model	Scenario	Region	Variable	Subannual	Unit	2050
SCOPE SD v1.0	Upload Test 1.0	Europe	Emissions|CO2	Year	Mt CO2/yr	88.95
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Solar	Year	EJ/yr	5.25
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Wind	Year	EJ/yr	5.42
SCOPE SD v1.0	Upload Test 1.0	Europe	Capacity|Electricity|Coal	Year	GW	0
SCOPE SD v1.0	Upload Test 1.0	Europe	Capacity|Electricity|Wind	Year	GW	495.96
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Biomass	Year	EJ/yr	0.01
SCOPE SD v1.0	Upload Test 1.0	Europe	Capacity|Electricity|Biomass	Year	GW	0.17
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Hydro	Year	EJ/yr	2.02
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Nuclear	Year	EJ/yr	0.26
SCOPE SD v1.0	Upload Test 1.0	Europe	Capacity|Electricity|Hydro	Year	GW	218.05
SCOPE SD v1.0	Upload Test 1.0	Europe	Capacity|Electricity|Oil	Year	GW	0
SCOPE SD v1.0	Upload Test 1.0	Europe	Secondary Energy|Electricity|Oil	Year	EJ/yr	0

Source						Years
Model	Scenario	Region	Variable	Subannual	Unit	2050
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Solar	Year	EJ/yr	0.67
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Wind	Year	EJ/yr	0.96
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Biomass	Year	EJ/yr	0
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Hydro	Year	EJ/yr	0.2
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Nuclear	Year	EJ/yr	0.16
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Oil	Year	EJ/yr	0
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Coal	Year	EJ/yr	0
SCOPE SD v1.0	Upload Test 1.0	France	Secondary Energy|Electricity|Other	Year	EJ/yr	0.04

Figure 31: Creating a workspace at the openENTRANCE Scenario Explorer with test data from SCOPE SD

3.5 Case Study 5 - Decentralization

3.5.1 Case study objective, challenges and beyond the state of the art

The objective of CS 5 is to assess the (modelled) impact of decentralization on investment decisions. Decentralization can be interpreted as:

- Decentralization of targets: e.g. member state targets for GreenHouse Gas (GHG) emissions or Renewable Energy Sources (RES) share in the generation mix vs. European global targets;
- Decentralization of decisions: local optimization vs global optimization.

In this case study we will compare the three following variants:

1. Global decision and global target: in terms of mathematical optimization, the problem is formalized with a single cost function representing investment and operational costs and constraints related to technical constraints as well as ecological targets in terms of emissions or renewable penetration (proportion of renewable sources in the electricity mix);

2. Global decision and local target: this setting corresponds to an optimization problem with the same cost function and technical constraints as above, except that ecological targets are locally imposed to each region instead of globally to the whole system;
3. Local decision and local target: this framework differs from the previous ones because it involves several optimization problems since each region aims at minimizing her own costs under technical constraints while guarantying her own ecological targets. However, we have to make assumptions on potential exchanges between regions or between regions and a central operator.

Each variant performs the role of fictional central planners with all information and making investment decisions at the global level (variant 1 and 2), or at local levels (variant 3) in order to minimize total (global or local) system costs.

This case study should then illustrate to what extent different decision levels (region, country, Europe) with specific objectives may lead to different investment decisions.

Scope of technologies:

- Nuclear Power Plants;
- Combine Cycle Gas Turbine with and without CCS (carbon capture and storage);
- Open Cycle Gas Turbine;
- Hard coal steam power plant with and without CCS;
- Lignite steam power plant with and without CCS;
- Biomass and waste incineration (steam power plant);
- Hydro generation (storage reservoir, pumped storage and run-of-river);
- Solar PV;
- Wind Onshore and Offshore;
- Electric transmission and distribution grid;
- Storages: including batteries and e-mobility.

Most of the existing capacity expansion models rely on deterministic linear programming approach. The variables that typically would be uncertain (electricity demand, inflows, variable renewable production profiles, etc.) are taken as given, and the model optimizes with perfect foresight over some representative days or along successive time steps. Similarly, to avoid complexity, network power flows and power plants technical constraints are also usually excluded (ramping constraints, minimum uptime and minimum downtime constraints).

However, the cost of renewable sources integration into the electrical system is mainly due to the fact that it naturally increases the flexibility needs of the system in order to guarantee feasibility. Indeed, new flexibilities are required to be able to achieve the balance between supply and demand at each time step, in spite of the deterministic and stochastic variability of variable renewable generation.

It is then crucial to fully integrate this increase of flexibility needs in investment decisions. To this end, one must rely on a capacity expansion tool with both

- a refined description of technical constraints related to the flexibility levers (such as power plants, batteries, demand side management or network);

- a stochastic framework allowing to model uncertainties inherent to variable renewable generation.

This setting is strongly challenging, in various aspects

- data and model aspects: providing a detailed and comprehensive description of the system requires to gather a large amount of data and to be judiciously aggregated according to relevant models;
- algorithmic and computational aspects: the size of the related optimization problem is huge and requires cutting-edge tools to be able to obtain results in reasonable times.

The present case study will rely on the openENTRANCE Scenarios (from WP3) and on the Plan4res public dataset to propose an attempt in that challenging direction.

3.5.2 Detailed methodology of the case study: modus operandi

5 focuses on the Pan-European electricity sector in the single year, e.g. 2050 and includes the countries which are to be decided. A first analysis will be conducted with France and her sub-regions. Optionally, if data are available, we will extend the analysis with Europe and her Members-states. In order to obtain the total system costs we have to determine the fixed and variable costs. As we simulate only one single year, we will compute annual costs:

- annual fixed costs are the investment costs and the annualized fixed operational costs;
- variable costs are the annual power plant operational costs (fuel & CO2 emission price).

Then the operational costs (related to the optimal dispatch) will be computed by the scenario valuation layer of plan4EU while the investment decision will be provided by the capacity expansion layer.

The geographical perimeter is to be decided (and will depend of the computation feasibility and data availability) e.g. Europe vs Countries / France vs French regions / Germany vs German landers… In a first option we will consider France and its sub-regions and the workflow will be precisely described in this case.

The 3 variants that will be run are detailed below from the European/member states example:

1. Global European renewable capacity target (% of the electricity mix) with global optimization of the European electricity mix (=as if all decisions were centralized at European level)

   ⇨ 1 Full plan4EU run with a global constraint on RES target

2. “Local” Member-state renewable capacity targets (% of each country electricity mix) with global optimization of the European electricity mix (=as if all decisions were centralized at European level)

   ⇨ 1 Full plan4EU run with constraints on RES target at the level of each country

3. “Local” member-state renewable capacity targets (% of each country electricity mix) while each country optimizes its electricity mix (with import/export assumptions)

   ⇨ N (number of countries) runs of Full plan4EU at country-scale

   ⇨ 1 run of plan4EU SSV+EUC to evaluate the costs

The following steps will be performed:

a) chose the geographical scope: define the global level and the local regions. A first run of this case study will be done on France (as global level) and its regions (as local regions). Potential extensions could be considered with Europe (as global level) and its member state (as local regions) may be performed later.

b) define the set of possible investments at global or local level (in which technology may each level invest? This will deeply depend on the chosen level as countries may have different opportunities than local sub-country regions)

c) investigate the question: which level is deciding of grid extensions? (This will of course also depend of the geographical scope chosen).

d) chose the starting point: it could be a reference mix for 2050 in the chosen region.

3.5.3 Expected results and limitations

General results

The general expected results are a quantification of the impacts of decentralization of investment decisions on the global investment cost and operational cost of the electrical system as well as on the prices and the technical operation of the electric system. In particular, this case study could bring relevant recommendations as for the coordination/alternative structures to set up in order to minimize de-optimizations of the system.

Specific results

More specifically, plan4EU will provide several indicators in terms of which the three variants could be compared such as: operation costs; renewable curtailment level; pollutant/CO2 emissions; network congestions; dual variables (that can be interpreted as prices) related to demand constraints or capacity limits of power lines. It is also possible to investigate the variability of those indicators by simulating the operation decisions on several scenario of uncertainties.

Limitations

The main limitations of the case study are listed below

- Modelling the power system only without a fully multi-energy and inter-sectoral approach;
- Modelling the power system on a single year operation (2050 horizon), without providing any pathway to reach the final electricity mix;
- Aggregation of hydro generation (one lake by country/region, no hydro valleys);
- Clustering of transmission network;
- Modelling of distribution network is limited to the reinforcement's costs and global constraints at each node of the transmission network (maximum amount of power injected into the distribution network at each hour);
- Synthetic inertia is not modelled.
-

However, this study is not meant to determine the exact cost and system reliability associated with high renewable energy penetration, but is intended to compare investment decisions resulting from different level of decentralization. In that comparative analysis perspective, our case study should still bring relevant information in spite of the highlighted limitations.

3.5.4 Set of models

CS 5 only involves a single model plan4EU, whose lead partner and main functionality are provided in the table below.

Table 9. Plan4EU model

MODEL	LEAD PARTNER	MAIN OBJECTIVE
Plan4EU	EDF	To optimize least-cost power system investments and operation

Table 10. Summary of model requirements

	Geography		Time		Technological scope
	Horizon	Granularity	Horizon	Granularity	
Plan4EU	France	France and its sub-regions defined as in ehighway2050 clusters (defined in Nomenclature)	1 year (2050)	Hourly (weekly for water values)	Electricity generation, storage, uses (both flexible and inflexible) as well transmission and distribution grid.

Model type and problem:

The model implemented in plan4EU simultaneously optimizes investment decisions and hourly dispatch over the course of one year (2050) relying on the two following modelling layers.

Capacity expansion model

The capacity expansion model will compute a better or ideally optimal set of assets including electric generation plants, storages, interconnection capacities between clusters and distribution grid capacities, for the considered time horizon (the year 2050). Here optimal means, providing the least-cost set of assets, while accounting at best for the modelled constraints.

Scenario valuation layer

The Scenario valuation layer will evaluate the investment decisions from the capacity expansion model by means of modelling the operation of the existing assets in the energy system. This layer contains two distinct models, the first model will be referred to as the seasonal storage valuation model and the second model will be the European unit commitment (EUC) model.

The objective of the seasonal storage valuation model is to provide an accurate account of "the value" that seasonal storage can bring to the system. Indeed, such seasonal storage (e.g., cascaded reservoir systems) can be used to store energy over large spans of time and use this "stored" energy when most needed. The actual use may in particular depend on adverse climatic situations (intense cold), but the ability to store the energy may in turn also depends on climatic conditions (e.g. draught). It is therefore clear that such a vision of value should be transferred in an appropriate way to shorter time span tools, such as the EUC model. In turn computing an accurate value intrinsically depends on the value of substitution, and thus ultimately on the EUC tool as well.

The EUC model will compute an optimal (or near optimal) schedule for all the system assets satisfying the set of constraints:

- power demand supply;
- ancillary services supply;
- minimal inertia in the system;
- maximum transmission and distribution capacities between clusters;
- technical constraints of all assets.

Input data

Input variables are described in the list below. The geographical perimeter considered here is limited to France and its sub-regions (in a first approach) with a geographical granularity corresponding to Ehighway 2050 sub-regions as defined in the openENTRANCE nomenclature. The time horizon is year 2050 with a time granularity of one hour for most of the considered time series except for seasonal storage values that will be computed by plan4EU on a weekly granularity for the whole year 2050. As much as possible, input data will be provided by openENTRANCE scenarios (provided by

WP3, see chapter 2 of this report). When this is not possible (mainly because of the time or geographical granularity required by plan4EU is more refined), plan4EU will provide its own input data consistently with openENTRANCE scenario.

- Initial (aggregated) transmission and distribution grid (in France in 2050): defined as a list of cluster nodes (one pair of transmission and distribution node for each cluster) and lines between nodes with maximal capacity (MW);
- Initial generation mix (in France, in 2050): initial installed capacities in each type of generation plant (thermal, hydro, etc) or storage technology at each node of the grid determined by a vector of installed capacity (GW) ;
- Potentials of renewables at each node of the grid (GW);
- Electricity demand energy for year 2050 per use (EJ/yr);
- Electricity primary and secondary reserve (ancillary services) requirements (MW);
- Electricity demand inertia (s);
- Generation profiles for wind, Solar PV, hydro inflows, run of river, correlated to meteorological scenario given as a set of hourly time series for each node and correlated to meteorological scenario (%);
- Electricity demand profiles correlated to meteorological scenario given as hourly time series for each node and correlated to meteorological scenario (%);
- Financial and technical parameters of each technology (power plants, storage, fuel prices, hydro (reservoirs, run of river, pumped storage), …);
- Demand response types and potentials (including centralized (i.e. connected to a transmission node) or distributed (connected to a distribution node) load shifting, or curtailment);
- Investment costs in generation technologies (variable costs (US$2010/kW) and annualized fixed costs (billion US$2010/yr)) related to each generation technology for each grid node;
- Investment costs in transmission and distribution grid (Euros/MW) related to the interconnection capacity for each couple of cluster nodes;
- CO2 emission budget (Mt CO2/yr) defining the maximum allowed CO2 emissions for each CO2 zone (CO2 zones being defined as a partition of the set of cluster nodes);
- Boundaries: hourly time series representing electric power exchanges with not-accounted for neighbouring countries (MWh).

Output data

Output variables are described in the list below.

- (Quasi-)optimal generation mix and transmission and distribution grid investments vector of capacity (MW);
- (Quasi-)optimal investment costs (US$2010) in each technology;

- Operation schedules: one hourly time series for each flexibility unit (power plant, storage, demand response, hydro reservoirs…), correlated to meteorological scenario indicating power injected or withdrawn from the grid (MWh);
- Generation of the variable renewable generation units (Wind, solar PV) including curtailment (MWh);
- CO2 emissions (ton);
- Electricity not served (loss of load) (MWh);
- Marginal costs (or price signals) related to coupling constraints (electricity demand, reserve requirements, inertia demand, CO2 budget and grid congestions): one time series per constraint zone correlated to meteorological scenario (US$2010/MWh or US$2010/Mt for CO2 constraint or US$2010/MW for grid congestions).

The Figure 32 gives schematic overview of plan4EU including the capacity expansion layer and the scenario valuations layers (Seasonal Storage Valuation and European Unit Commitment).

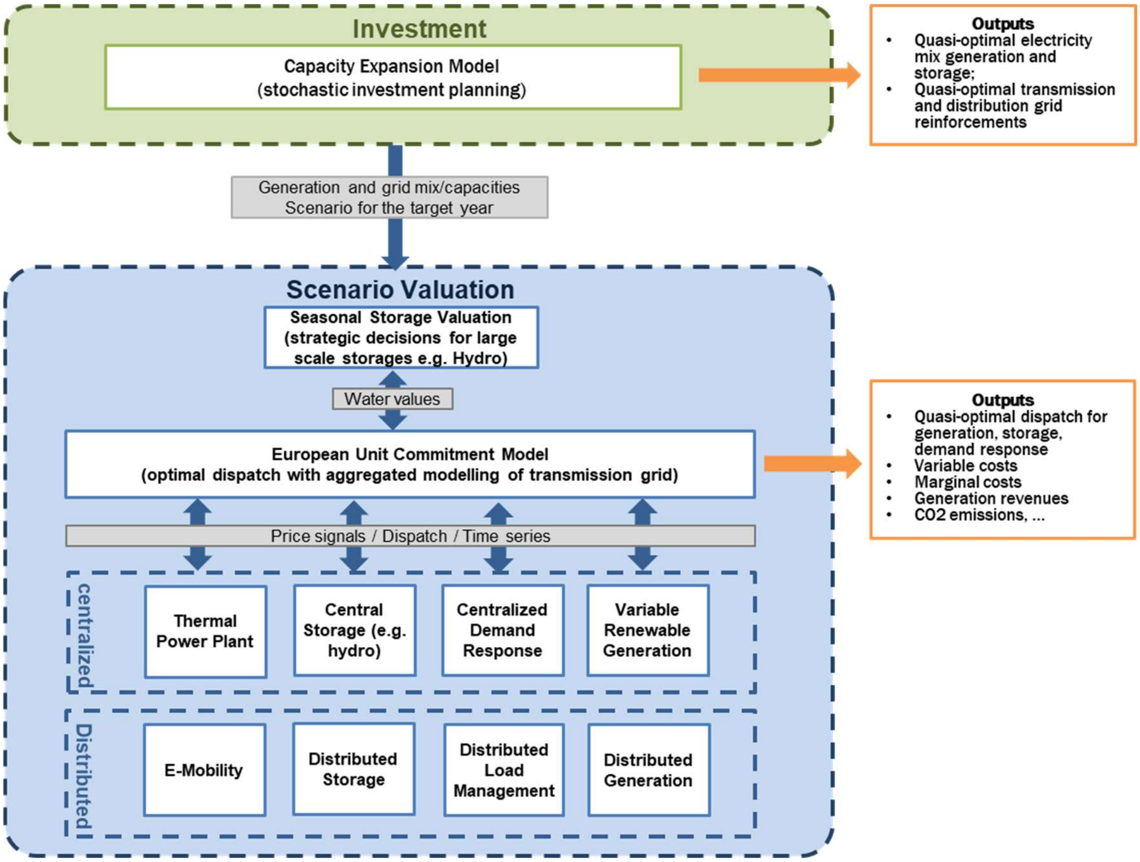


Figure 32: Schematic overview of the plan4EU modelling framework

3.5.5 Workflow of the case study

This section presents, in a clear and simple manner, the workflow of CS5. As already mentioned, CS5 will first consider decentralization of investment decisions in the case of France and the associated sub-regions. Optionally, if data are available, this analysis will be conducted with Europe and Members-states. For the sake of simplicity, the workflow is presented here in the first case of application (France and its sub-regions).

General workflow

A wide perspective of the workflow is presented by the diagram below.

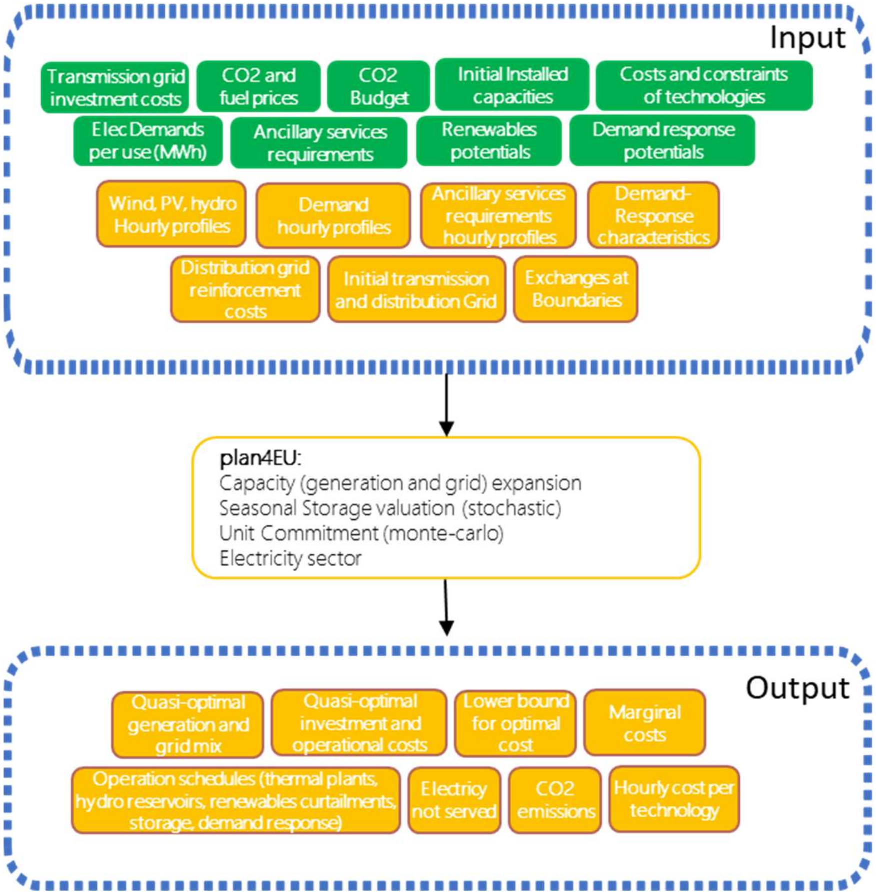


Figure 33 : CS5 general Workflow

The colour code used in the above figure is

- Green for data from openENTRANCE Scenarios

- Orange for specific input data to plan4EU model, that will be uploaded to openENTRANCE database

3.5.6 General list of data

Ideally, CS5 will rely as much as possible on data provided by openENTRANCE scenarios. However, CS5 requires refined granularities at three main levels:

a) geographical level (considering regions in France);
b) time level (hour);
c) uncertainty level (several scenario correlated to temperature are also required).

Hence, often we need to disaggregate annual values provided by openENTRANCE scenario into hourly profiles correlated to temperature. This disaggregation will be done based on plan4EU data. In particular, plan4EU will provide hourly profiles (in %), also referred to as *load factors* allowing to operate that disaggregation for inflows, run-of-river, wind or solar PV potentials etc.

List of data that are or will be on the openENTRANCE platform

All those data are either already on the openENTRANCE database or are going to be uploaded to the platform during the project. As already mentioned, in the first approach considered by CS5 and described here, the geographical perimeter is limited to France and its sub-regions (in a first approach) with a time horizon year 2050. This perimeter is then often made implicit in the following list.

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Initial Installed capacities per technology in 2050
- Potential of renewable energy in 2050
- Electricity demand in MWh (annual energy) per country per use in 2050
- Ancillary services reserve requirements (MW)
- Costs of technologies
- CO2 and fuel prices
- CO2 budget
- Power technologies with their financial and technical parameters
- Storage technologies
- Demand response technologies and potentials
- Investment costs for the transmission grid
- Reinforcement costs for the distribution grid (if available)
- Boundaries: electric power exchanges with not-accounted for neighbouring countries (if available)

Data coming from plan4EU database

- Electricity demand profiles correlated to temperature time series

- Inertia demand (s)
- Other profiles correlated to temperature (solar PV, wind, run-of-river, inflows etc.)
- Hydro technologies with their technical parameters (reservoirs, run of river, pumped storage)
- Initial transmission and distribution grid
- Reinforcement costs for the distribution grid (if not available from openENTRANCE scenario)
- Boundaries: electric power exchanges with not-accounted for neighbouring countries (if not available from openENTRANCE scenario)

Data produced during the case study exercise as outputs of plan4EU

This data will be uploaded to openENTRANCE database

- Quasi-optimal mix (generation and transmission and distribution grid)
- Quasi-optimal investment and operational costs
- Marginal costs (associated with coupling constraints : demand, ancillary services and inertia requirements, CO2 budget, congestion)
- Electricity not served (loss of load)
- CO2 emissions
- Flexibilities schedules: hourly profiles for power plants, wind, solar PV, hydro, storage, demand response, correlated to meteorological time series

3.5.7 Data workflow

The specificities of the data exchanged among models are presented in this section.

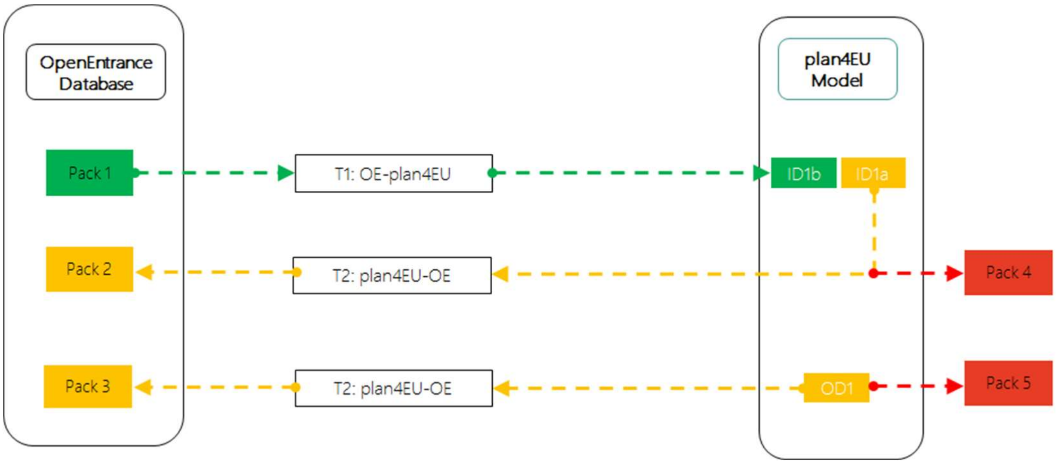


Figure 34 : Data workflow

The colour code used in the above figure denotes:

- Green for data from openENTRANCE Scenarios

- Orange for specific input data to plan4EU model, that will be uploaded to openENTRANCE database
- Red: specific data to one model, that are not going to be uploaded to openENTRANCE database nor shared with anyone

Pack 1, Pack2 and Pack4 will be precisely determined depending on what input data are available from openENTRANCE scenario. As much as possible CS5 will rely on openENTRANCE scenario. However, when some data are not available, plan4EU will resort to alternate public data or to ***EDF confidential data***. In this latter case, some input data will automatically be confidential (implying Pack4), similarly some output data may inherit that confidentiality property (implying Pack5). However, at this stage, without the exact description of what data are really provided by openENTRANCE scenario the description of Pack4 and Pack5 cannot be further developed.

A list of specific dataPacks is as follows:

dataPack	Data flow	Content,
Pack 1	Input data from OE scenarios	Initial Installed capacities in France per technology in 2050 (MW) Potential of renewable energy in 2050 (MWh) Electricity demand in MWh (annual energy) per country per use in 2050 Costs of technology CO2 and fuel prices CO2 budget and emissions per technology (derived from total emissions in scenarios) Power and Storage technologies: financial and technical parameters Investment costs for transmission, generation and storage Boundaries: electric power exchanges with not-accounted for neighbouring countries (if available from openENTRANCE scenario)
Pack 2	Input data from Plan4EU database	Electricity demand in MWh (annual energy) per country per use in 2050 (for uses that are not detailed in Scenarios: cooling) Electricity demand in MWh (annual energy) per cluster per use in 2050 (for uses that are not detailed in Scenarios: cooling) Initial Installed capacities per cluster per technology in 2050 (MW) Electricity Demand profiles correlated to temperature time series Other profiles correlated to temperature (solar PV, wind, run-of-river, inflows etc.) Demand response technologies and potentials Power technologies technical parameters (for those not available in scenarios) Initial transmission and distribution grid with flow constraints Ancillary services reserve requirements Potentials of Demand response in 2050
Pack 4	Input data from Plan4EU database	Hydro technologies with their technical parameters (lakes, run of river, pumped storage) Reinforcement costs for the distribution grid (if not available from openENTRANCE scenario)

		Boundaries: electric power exchanges with not-accounted for neighbouring countries (if not available from openENTRANCE scenario)
Pack 3	Output data from Plan4EU	Quasi-optimal mix (generation and transmission and distribution grid) ? Quasi-optimal investment and operational costs ? Marginal costs (associated with coupling constraints: demand, ancillary services requirements, inertia, CO2 budget, congestion) ? Electricity not served (loss of load) ? Hourly cost per technology ? CO2 emissions ? Flexibilities schedules: hourly profiles for power plants, wind, solar PV, hydro, storage, demand response, correlated to meteorological time series ?
Pack 5	Output data from Plan4EU	Quasi-optimal mix (generation and transmission and distribution grid) ? Quasi-optimal investment and operational costs ? Marginal costs (associated with coupling constraints : demand, inertia, ancillary services requirements, CO2 budget, congestion) ? Electricity not served (loss of load) ? Hourly cost per technology ? CO2 emissions ? Flexibilities schedules: hourly profiles for power plants, wind, solar PV, hydro, storage, demand response, correlated to meteorological time series ?

List of Datasets (using the models own formats):

ID1a	Input dataset **"part a"** that comes from the own **plan4EU**'s database
ID1b	Input dataset **"part b"** that comes from the openENTRANCE database to **plan4EU**
OD1	Output dataset from **plan4EU** to openENTRANCE database

3.5.8 Data-exchange tools

Two data-exchange tools must be implemented to perform the linkage between plan4EU data and the Common data format.

T1 (OE-plan4EU)	Set of tools or methods to convert data from the **Common data format** to **plan4EU format**
T2 (plan4EU-OE)	Set of tools or methods to convert data from **plan4EU output format** to **Common data format**

3.5.9 Execution order

This section provides the stepwise plan to carry out the case study, specifying the data exchanged.

10. **Extraction of data from openENTRANCE Database:** First, the Pack 1 is built by selecting the adequate variables. Pack1 is structured according to the common nomenclature. It is transformed through T1 into plan4EU data formats ID1b

11. **Building plan4EU Input dataset and running plan4EU**: The plan4EU dataset is built out of plan4EU own data (ID1a), openENTRANCE Scenario data (ID1b). ID1a can be transformed into openENTRANCE Data format using T2 and uploaded to openENTRANCE database, producing Pack 2. Plan4EU is ran, which produces the Output OD1. OD1 can be converted to openENTRANCE format by T2 and uploaded to openENTRANCE Platform, producing Pack3 and Pack 5.

3.5.10 Implementation in the openENTRANCE scenario Explorer (screenshot)

A file containing a subset of plan4eu input data (i.e. some data from plan4eu public dataset[26] , containing only variables that are not requiring hourly timeseries, and 2/are already implemented in the openENTRANCE nomenclature, and regions that are already implemented in the nomenclature) has been created using the plan4eu-to-iamc conversion tool, and validated using the validation function included in the nomenclature. The file has been uploaded to the openENTRANCE scenario explorer.

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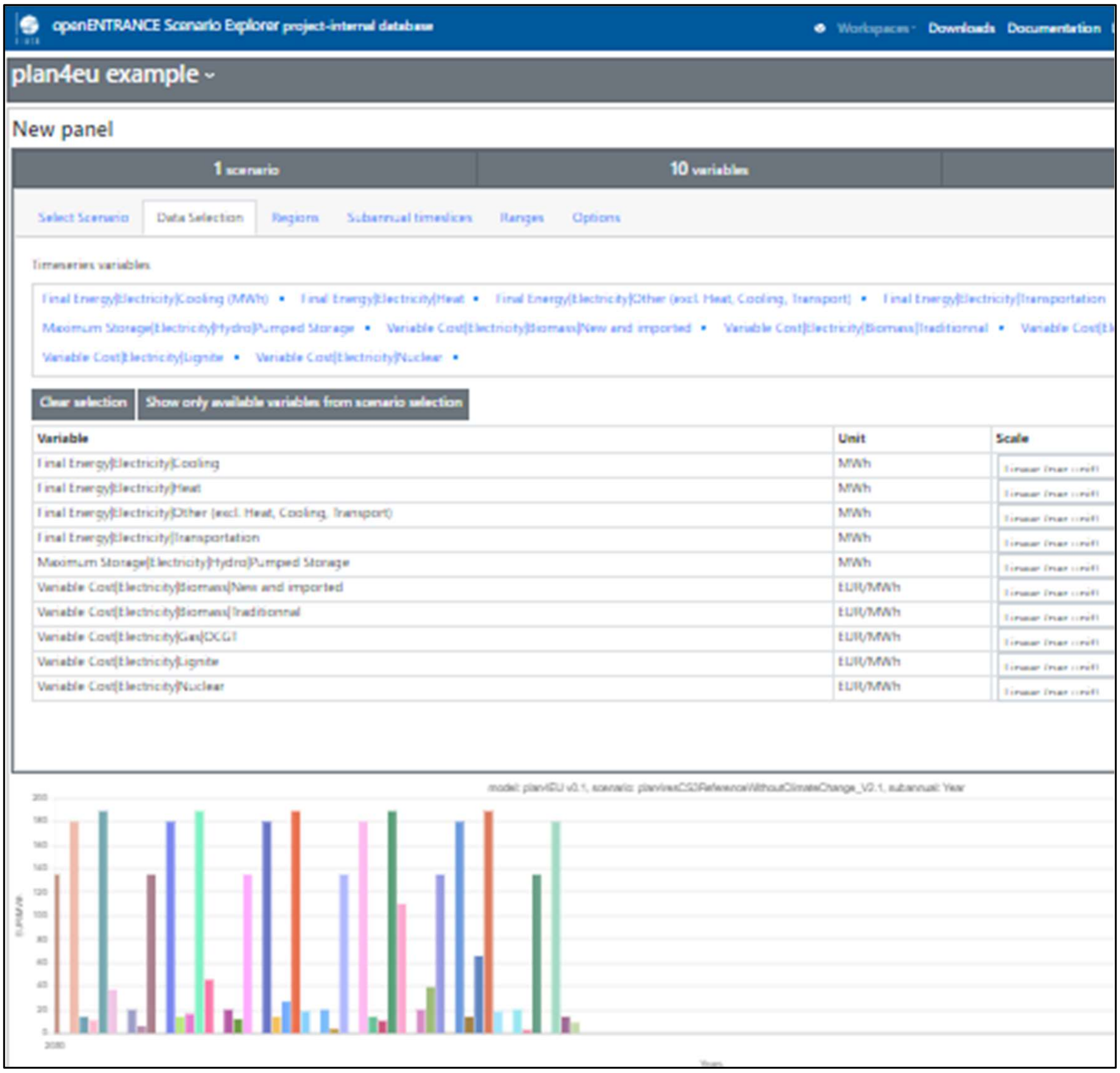
[26] https://zenodo.org/record/3802550



Timeseries variables

Final Energy|Electricity|Cooling (MWh) • Final Energy|Electricity|Heat • Final Energy|Electricity|Other (excl. Heat, Cooling, Transport) • Final Energy|Electricity|Transportation
Maximum Storage|Electricity|Hydro|Pumped Storage • Variable Cost|Electricity|Biomass|New and imported • Variable Cost|Electricity|Biomass|Traditional • Variable Cost|El
Variable Cost|Electricity|Lignite • Variable Cost|Electricity|Nuclear •

Variable	Unit	Scale
Final Energy|Electricity|Cooling	MWh	
Final Energy|Electricity|Heat	MWh	
Final Energy|Electricity|Other (excl. Heat, Cooling, Transport)	MWh	
Final Energy|Electricity|Transportation	MWh	
Maximum Storage|Electricity|Hydro|Pumped Storage	MWh	
Variable Cost|Electricity|Biomass|New and imported	EUR/MWh	
Variable Cost|Electricity|Biomass|Traditional	EUR/MWh	
Variable Cost|Electricity|Gas|OCGT	EUR/MWh	
Variable Cost|Electricity|Lignite	EUR/MWh	
Variable Cost|Electricity|Nuclear	EUR/MWh	

Figure 35: Example of screenshot on Plan4EU workspace in the openENTRANCE scenario explorer.

3.6 Case Study 6- Innovative Technologies

3.6.1 Case study objective, challenges and beyond the state of the art

The main objective of this case study is to investigate and develop a better understanding of the potential of innovative technology, specifically the use of seasonal heat storage in a local micro energy system. This case study aims to quantify how seasonal heat storage can reduce the surplus heat encountered in the district heating system as well as the excess heat produced from solar heating during summer. Furthermore, it seeks to quantify the potential of thermal seasonal storage to cover peak loads in heat demand during winter and thereby reduce the need for investment in heating infrastructure, both in the current and for the future system. The case study will also include a cost/benefit analysis for the application of this novel storage technology as well as offer insights on how this technology can be relevant on a European level. This will be done through a qualitative discussion of the relevance of the results on the European level. The case study will also identify drivers as well as barriers for investment into this novel heat storage technology. In particular, the case study will focus on the district Furuset in Oslo and evaluate the innovative technology of seasonal storage in underground rocks in this setting. The interactions between the district heating system of the city of Oslo and the local heating grid will be investigated with hindsight to the impacts especially on the energy system at Furuset.

In the light of Europe's ambition to decarbonize its energy system, ever more intermittent energy sources will penetrate the energy market. It is likely that in many parts of Europe there will be an excess of energy supply during periods in the summer months from both solar and wind power. Short-term storage challenges might well be solved by the deployment of batteries on a large scale but for seasonal storage other technologies will be needed. With pumped storage being very limited to specific geographical conditions and hydrogen production and storage still facing efficiency issues, there is a clear need to assess other options. The results of this case study will give qualitative insights into what role local, seasonal heat storage can play on a pan-European scale in the transition to a decarbonized energy system.

It will furthermore inform the Norwegian national research centre on zero emission neighbourhoods in smart cities (ZEN), as well as the government in Oslo on the potential and benefits of seasonal thermal storage in connection with local energy system solutions across the country.

The model that will be used for the analysis is the energy investment model eTransport (Bakken et al. 2007[27], Kohlstadt et al. 2018[28]). A representation of the micro energy system of Furuset, created in the ZEN centre will be adapted to incorporate a module to represent the planned seasonal thermal energy storage unit (Kauko 2019[29]). This adapted version will serve as the baseline scenario and will be compared to a micro energy system without such a storage unit.
The central challenges of CS6 are:

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[27] Bakken, B. H., Skjelbred, H. I., & Wolfgang, O. (2007). eTransport: Investment planning in energy supply systems with multiple energy carriers. Energy, 32(9), 1676-1689.

[28] Kauko, Hanne (2019). ETRANSPORT MODULES FOR DIURNAL AND SEASONAL HEAT STORAGE - User guide and technical documentation. ZEN Memo No 15

[29] Kolstad, M. L., Backe, S., Wolfgang, O., & Sartori, I. (2018). Software tools for local energy system operation and expansion. Deliverable 5.1. 2/2017. ZEN Report.

i. The ambitious plan to upgrade Furuset to a climate-neutral neighbourhood, with its own micro energy system, is a challenge in itself. Mirroring this highly site-specific micro energy system combined with the planned installation of a novel energy storage technology using an existing energy systems model is a major challenge.
ii. A central challenge is the need to balance the level of detail in the energy systems description of the different energy carriers with the need for rather high time resolution in order to capture the effects of intermittent renewable energy integration as well as demand peaks.

The beyond state-of-the-art elements of CS6 are:

i. Including seasonal thermal storage into the energy system analysis
ii. Data from a real-world test case on a zero-emission neighbourhood with its own micro energy system that includes novel technology elements
iii. Discussion of the relevance of local results from a real-world test case of novel storage technology on the pan-European level

3.6.2 Detailed methodology of the case study: modus operandi

The eTransport model will be used to simulate the impact of a seasonal storage unit on the case of Furuset, Oslo. Within the ZEN centre a representation of the energy system of Furuset has been developed in eTransport. This will be used as the starting point and will be adjusted to include a seasonal thermal storage unit. This model description will function as the baseline throughout the case study. Analysis will be conducted on the ability of the pre-dimensioned thermal storage unit to supply peak demands of heat, especially during winter. This will be followed by a calculation of how much excess heat that without the thermal storage unit cannot be used, can be stored in the planned unit. As one of the important co-benefits of the installation of a seasonal thermal storage unit, less investment in expensive heating infrastructure to supply the new district with access to the district heating system is expected. We analyse the additional cost for the adjustment of existing infrastructure in the district heating system to supply Furuset with sufficient heating in absence of the thermal storage unit.

As a complementary element of the case study a cost/benefit analysis will be conducted of the thermal seasonal storage. This will include private economic costs to the company building the storage unit but also societal/communal costs regarding the installation phase. On the benefit side, environmental benefits as well as potential health and climate benefits also down the supply chain will be considered and elaborated on.

To better understand what affects investments beyond rational economic reasoning, the key actors in the Furuset case are intended to be interviewed. A qualitative assessment of the interviews is to yield better insight in the underlying drivers and barriers for investments which are until now not captured in the model.

Finally, a qualitative discussion of the potential of this novel type of seasonal heat storage on a pan-European level will be conducted. Since the seasonal storage in bed rock is dependent on the proximity of a high temperature heat supplier, the ground conditions and sufficient space, we will give an idea where in Europe this technology could be deployed. Given this insight, the results obtained from the Furuset case can be discussed on the European level to give a better understanding of the potential importance of this type of storage. Furthermore, we will provide an elaboration on challenges and advantages of this type of seasonal challenge in comparison to other seasonal storage types.

3.6.3 Expected results and limitations

This case study is to yield quantitative results as well as qualitative insights on the impacts of a seasonal thermal storage unit on a local micro energy system. The results can be categorized into general and specific:

General results

- A better understanding of the possibility and related impacts of the use of this type of novel, thermal seasonal storage in suitable locations across Europe
- A better understanding of drivers and limitations/barriers of investments in thermal seasonal storage units

Specific results

Quantitative results include:

- The estimated, potential reduction of unused surplus heat produced in summer from - in this case study - a waste treatment plant, as well as from solar heating through the use of a thermal seasonal storage unit.
- The capacity of such a storage unit to supply peak demand of heat during winter.
- The reduction in infrastructure investment compared to a case without seasonal thermal storage.
- A cost/benefit analysis for this type of novel technology for thermal seasonal storage.

A limitation within the assessment in CS6 is that the total storage capacity is a user-defined input to the seasonal thermal storage module that will be used. This means that the size of the storage is predefined and hence cannot be optimized. This is a key limitation to the available module, since – in case of modelling a not yet existing case – a good understanding of the technology used is necessary to ensure sensible input arguments for charge/discharge amounts of heat as well as heat losses. This poses a limitation since it is not always given that the modeller is sufficiently familiar with the characteristics of all the technologies modelled.

A further limitation in CS6 is that only already existing modules will be used in the modelling of the micro energy system of Furuset and hence only already coded technologies and connections/interactions can be modelled.

3.6.4 Set of models

Table 11. Sample of format the set of models

Models	Lead Partner	Main Objective
eTransport	SINTEF	Cost minimization for operation and investments in energy systems. Typically used for neighborhoud to city scale models.

Table 12. Sample of format for the summary of model requirements

	Geography		Time		Technological scope
	Horizon	**Granularity**	**Horizon**	**Granularity**	
eTransport	Any confined area (typically neighbourhoods, but can also be a continent)	Building block level	Typically, 1 hour for operational model and 20-50 years for investment analysis.	Hourly	• Conversion: Boiler, heat pump, CHP, CCGT, Storage • Biomass: supply, market, bulk transport • District heating: heat market, water heater, heat/warm water load, heat storage, seasonal storage, heat source, DH lines • Electricity: Power line, electricity source/load/marked, battery, ac/DC converter, residential area • Gas: Compressor, valve, gas source/market/load/node/ network pipe/storage • Oil supply • Waste supply • Hydrogen: Electrolyser, fuel cell, reformer, hydrogen market/load/pipeline/bulk transport • Cooling: Cold load/supply, heat sink (condenser), compression chiller

Model type and problem:

A tool for energy system planning within a confined area (taking surroundings into account)

- Multiple energy carriers (electricity, heat, cooling, biomass, waste, hydrogen, natural gas and oil)
- Optimizes hourly operation and future investments (type, time)
- Minimizes total energy system costs
- Models a confined area but included interactions with outside energy system
- Models a full year through four representative days, one for each season
- Each representative day is modelled at an hourly resolution

- Considers energy needs as well as peak loads
- Different sub-modules for different technologies
- New technology can be incorporated to assess its impact on the existing energy system demands
- Experts from each technology develop the corresponding sub-modules
- Operational optimization in AMPL
- Investment optimization in C++
- Realistic representation of the system operation: dynamics, operational constraints, interconnections
    - Possibility for end-to-end modelling, i.e. from generation to consumption, also parts
    - Timeframe: long term planning horizon
    - General technical constraints
        - Hourly resolution for optimization
        - Representative time slots to model a full year
    - Specific constraints to each technology module
    - Coupling constraints: Time coupling between seasons
    - Uncertainty:
        - input data for the scenarios for 2050, inherent uncertainty on macroeconomic future trajectories
        - Representative time slices
    - Inputs (the inputs are dependent on which particular modules will be used in the description of the case Furuset and will include the following)
        - Demand: power, heating, hot water, gas, cooling, hydrogen (in MWh/h)
        - Prices: power, gas, waste, oil, biomass (Euro/MWh)
        - Installed capacity: rooftop solar PV, heat supply, heat pumps, wind capacity, different storage types (battery, heat seasonal, heat daily, hydrogen) in MW and MWh
        - Investment costs: battery, solar PV, energy efficiency in buildings, heat pumps

Sub-model: module for seasonal thermal storage in rock

- The storage is supplied with heat through a supply point (heat exchanger to the district heating grid)
- The storage supplies heat to the local energy system
- The storage can either be charged or discharged
- 24-hour time horizon
- The total amount of heat supplied and extracted over one full year needs to be zero
- Inputs: i) Amount of heat supplied/extracted/lost during the seasons, ii) Storage characteristics: size, max charge/discharge rate, total daily flow, charge/discharge choice

Input data

Seasonal storage characteristics: Capacity in MWh, maximum charge rate in MW, maximum discharge rate in MW, and heat loss.

Other relevant input data:

- Demand in active power, for each unit in hourly resolution, MWh/h
- Demand for heating, for each unit in hourly resolution, MWh/h
- Demand for hot water, for each unit in hourly resolution, MWh/h
- Demand for gas, for each unit in hourly resolution, MWh/h
- Demand for cooling, for each unit in hourly resolution, MWh/h
- Demand for hydrogen, for each unit in hourly resolution, MWh/h
- Power prices, in hourly resolution, if different for each unit, Euro/MWh
- Gas prices, in hourly resolution, if different for each unit, Euro/MWh
- Waste prices, in hourly resolution, if different for each unit, Euro/MWh
- Oil prices, in hourly resolution, if different for each unit, Euro/MWh
- Bio prices, in hourly resolution, if different for each unit, Euro/MWh
- Installed capacity of rooftop PV, hourly profile, MW
- Installed capacity of heat supply, hourly profile, MW
- Installed capacity of batteries hourly profile, MW
- Installed capacity of daily heat storage, hourly profile, MW
- Installed capacity of heat pumps, hourly profile, MW
- Installed capacity of wind power, hourly profile, MW
- Installed capacity of hydrogen storage hourly profile, MW
- Transmission and distribution capacities

Output data

Rank list of investments in different technology options, by cost and investment type and timing

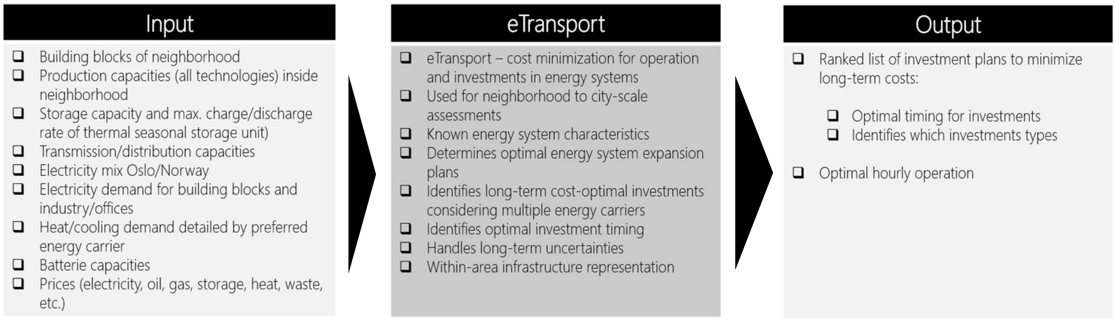


Figure 36: Schematic overview of the eTransport modelling framework developed at Sintef.

3.6.5 Workflow of the case study

This section presents, in a clear and simple manner, the workflow of the case study.

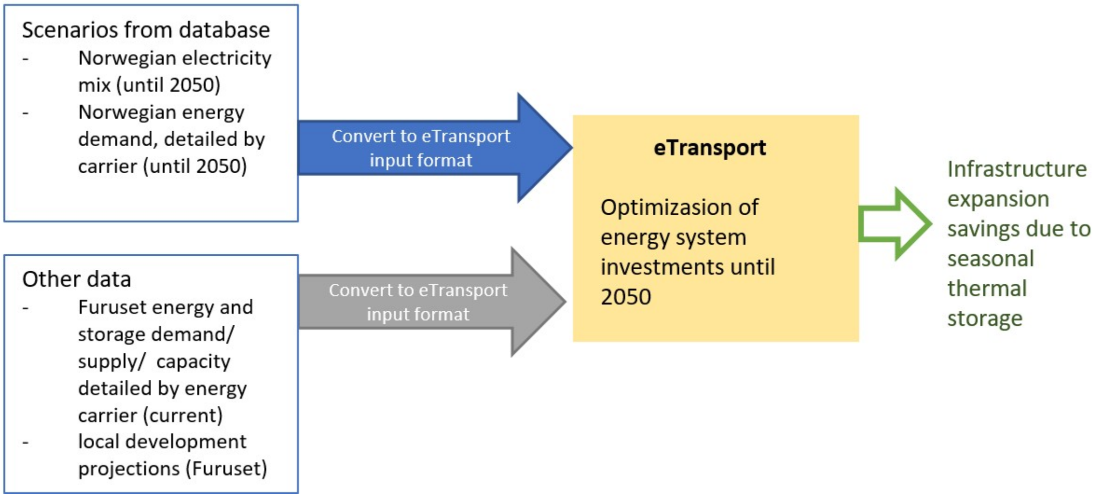


Figure 37: CS6 general Workflow

3.6.6 General list of data

For the energy systems characteristics outside Furuset, especially electricity supplied to the area, we will use the data provided by openENTRANCE scenarios. In the case that eTransport requires a higher temporal resolution than what can be obtained from the data developed in the openENTRANCE, the data will be disaggregated to the necessary level of detail using auxiliary datasets as proxies. This will be done in close accordance with other case studies, who encounter the same disaggregation exercise to ensure best possible coherence and comparability between results obtained in the different case studies.

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Electricity mix of Norway (scenario work – until 2050)
- Energy demand in Norway per use until 2050

Data coming from modelling teams own databases

- Characteristics of storage technologies
- Electricity demand in modelled area
- Heat and cooling demand in modelled area
- Local energy supply in modelled area
- Prices for energy carriers (hydrogen/gas/oil, etc.)
- Energy supply (capacity and carrier) in modelled area
- Transmission/distribution capacity
- Local storage options (capacity and costs)

Data produced during the case study exercise (mainly outputs of models)

- Potential savings (NOK and pot. CO2) from reduced infrastructure expansion
- Optimal energy system investment design

3.6.7 Data workflow

In this case study the focus is on investigating the potential of the novel technology of seasonal thermal storage in rock formations. There will only be used one model, the eTransport model and hence no data will be exchanged between models. However, scenario data from the openENTRANCE scenarios will be used. No data will be uploaded to the openENTRANCE database (see Figure 38).

Figure 38 illustrates the following flow:

- The openENTRANCE database provides scenario information.
- There is only one model used and it receives data from the open database and from external sources
- There is one tool converting the data from the Common Data format of the Database to the input data format of the model (**T1**)
- Dashed lines represent the flow of information

It is considered 2 types of dataPacks:

- Whose content comes from openENTRANCE scenarios (**Pack1**)
- Whose content comes from mode's own database **(Pack 2)**

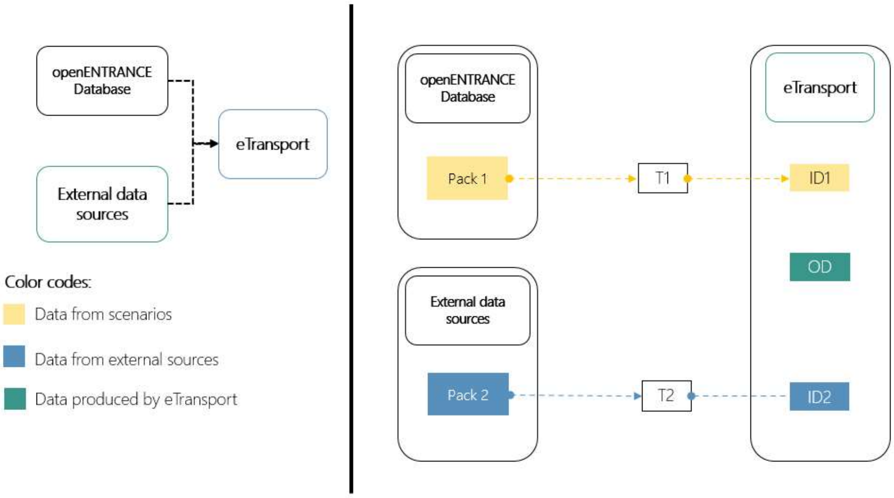


Figure 38: Data workflow

dataPack	Data flow	Content, as example:

Pack 1	Input data from Scenarios, common between models	Technology operation costs Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data from external sources	Generation profiles for wind, PV, hydro correlated to meteorological time series Other generation profiles (biomass for example) Electricity Demand profiles correlated to temperature time series (including electric vehicle profile) Power and storage technologies with their financial and technical parameters Prices for relevant energy carriers Transmission capacities Local distribution capacities (heat and electricity)

List of Datasets (using the models own formats):

ID1	Input dataset "**1**" that comes from the openENTRANCE database to **eTransport**, *i.e. energy demand and Norwegian/European energy mix, etc.*
ID2	Input dataset **"2"** that comes from external data sources to **eTransport**, *i.e. Electricity demand*
OD	Output dataset from **eTransport**, *i.e. optimal investment path*

3.6.8 Data-exchange tools

Two data-exchange tools need to be implemented to perform the linkage of data from the OE platform and external sources to the eTRansport model. These tools (or translators) will include:

- Unit conversions (e.g. EJ to MWh, MWh to GWh). (using the unit conversion available in OE platform)
- Geographical aggregation or disaggregation (using aggregation/disaggregation functions available in OE platform)
- Temporal aggregation or disaggregation (using aggregation/disaggregation functions available in OE platform)
- Formatting: i.e., converting the excel format to the adequate format. (columns, rows…)

T1 (OE-Model 1)	Set of tools or methods to convert data from the **Common data format** to **eTransport format**
T2 (ext.-Model 2)	Set of tools or methods to convert **external data formats** to **eTransport formats**

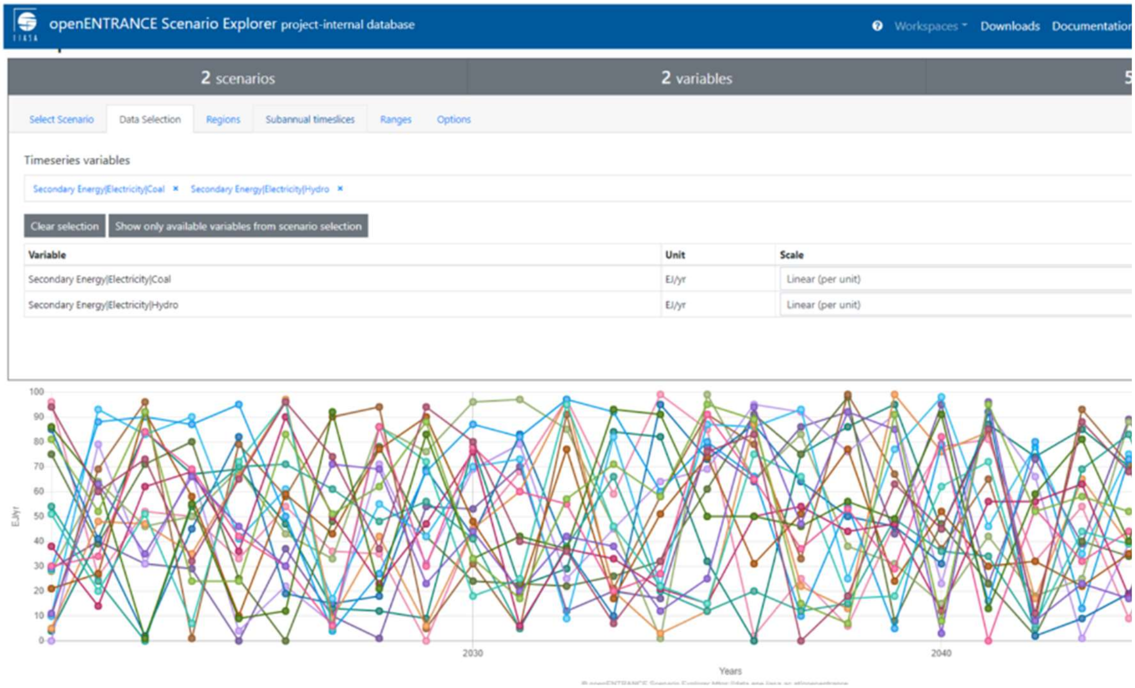
3.6.9 Execution order

This section provides a stepwise plan to carry out the case study, specifying the data and the relevant data-exchange tools:

1. **Extraction of data from openENTRANCE Database:** First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T1** into **eTransport** data formats **ID1**.

2. **<u>Building eTransport's input dataset and running eTransport:</u>** The eTransport indata dataset is built out of data from external sources (which are converted to the eTransport dataformat trough **T2**) to a dataset in the right input format (**ID1**) and openENTRANCE Scenario data (**ID2**). eTransport is executed and produces outputs **OD.** The output will not be shared on the open platform and is analysed and used only in this particular case study.

3.6.10 Implementation in the openENTRANCE scenario Explorer (screenshot)



Timeseries variables

Secondary Energy|Electricity|Coal × Secondary Energy|Electricity|Hydro ×

Variable	Unit	Scale
Secondary Energy|Electricity|Coal	EJ/yr	Linear (per unit)
Secondary Energy|Electricity|Hydro	EJ/yr	Linear (per unit)

Figure 39: Screenshot illustrating eTransport workspace in the openENTRANCE scenario explorer

As of now (time of writing this deliverable), there no results obtained from this case study. Also, eTransport is not yet one of the open models of the project. The case study qualitative insights are highly relevant for the future development of an integrated and decarbonized pan-European energy system and will be shared in form of a scientific article and other deliverables to the project. To ensure that all the modelling teams hold the competence to share data on openENTRANCE scenario explorer in the future, the team behind case study 6 has shared a dataset with random data (see figure above) to the openENTRANCE scenario explorer to assure the model interfaces with this database.

3.7 Case Study 7- Unlocking flexibility from the sector coupling

3.7.1 Case study objective, challenges and beyond the state of the art

Challenges related to keeping a high security of supply have raised while the share of intermittent renewable electricity generation is increasing, especially considering high EU targets for 2050. These variations must be handled in an optimal way. Some sector coupling, conventional generation units and demand response must be used to compensate RES power production variations in the power system and in this way, maintain the balance between production and consumption. Recently, a number of studies focused on investigating different options to unlock available flexibility from not only generators but also distributed energy resources (DERs).

Having a huge share of wind power, Denmark is an international leader in the implementations of a renewable, efficient, and secure energy system. The intermittent and not predictable characteristics of wind power leads to imbalances between power generation and consumption in the grid. To keep the power system management reliable and balanced flexible sources are needed on different time scales. The further increase in wind power integration will cause the extra need for flexibility to maintain the system secure and balanced in every instant in the time.

To support increasing share of wind power in the system, Denmark has undertaken efficient measures to enable a secured and balanced system. Through combined heat and power (CHP) plants, electric boilers and heat pumps (HP), the Danish power system has a close cooperation with the heating sector. In the process of integrating wind power in the system, a potential flexibility can be offered by the consideration of CHP plants. Moreover, CHP units have an important role in the Danish district heating (DH) network. In addition, the electricity taxes were profoundly reduced in 2013, bringing incentives to produce heat from electric boilers and HPs. To conclude, unlocking flexibility from the heating sector creates a solid ground for Denmark to integrate even more wind in the system.

Therefore, the Danish case study aims at investigating whether the integration of the heat sector enables us to unchain enough flexibility to ensure smooth and secure operation of future Danish energy system. (National level).

The central challenges of CS7are:

- Generating representative scenario of 2050 for Danish power system
- Scaling up the local pilot results for the whole Denmark

3.7.2 Detailed methodology of the case study: modus operandi

The investigation of CS7 will be carried out in the following steps:

- Running plan4EU model for the case of Denmark – obtaining hourly marginal prices in the power sector
- simulating balancing market with hourly resolution
- applying price-based control in the heating sector using the Frigg modelling framework – obtaining a new power and heat demand curves
- Running the plan4EU model again with the new inputs

The plan4EU model (EDF, linked) will be used for the implementation of the 1st step. Description of plan4EU model is provided in section 6.4. The 2nd step will be carried out using the results from the pilot study at DTU (see the detailed pilot description in the methodology section 8.6). The local pilot results will be scaled-up for the whole Denmark using the Frigg modelling framework and integrated with the openENTRANCE database. Finally, the impacts will be assessed by running the plan4EU model.

Plan4EU modelling framework

CS7 will make use of the European Unit Commitment model of Plan4EU which computes an optimal (or near optimal) schedule for all the system assets on a typical period of one year, with a typical granularity of one hour in order to satisfy demand and ancillary services at the lowest cost. It ensures that the given system is « feasible » in the sense that at each hour of the year, including peak hours, it is able to fulfil the following constraints

- power demand supply;
- ancillary services supply;
- minimal inertia in the system;
- maximum transmission and distribution capacities between clusters;
- technical constraints of all assets.

Frigg modelling framework

Frigg is a modelling framework for flexible energy systems. Energy flexibility, in the form of end-consumer demand response, is considered as a means of cost reduction in an integrated energy system, allowing for the efficient coupling of heat and power supply. Rather than being directly controllable, flexible demand, as a response to dynamic pricing of power and heat, is modelled through stochastic differential equations in order to account for the non-linearity of end-consumer behaviour.

The framework comprises of the following steps:

- finding the dynamic pricing cost-optimal for the energy aggregator
- generating altered demand profiles
- determining the cost-optimal dispatch and investment portfolio under demand response

The third point can be replaced by other models that are then soft-linked with the Frigg. In this case study, the optimal dispatch will be provided by the Plan4EU model.

3.7.3 Expected results and limitations

General results

Impact of coupling power and heat sectors on the flexibility of the energy system in general.

Specific results

Hourly marginal prices for the simulated power system in 2050. Commitment of different units. Level of curtailed electricity before and after implementation of flexibility. Important novelty is that the increased flexibility will be used when carrying out capacity extension planning.

Limitations

- The plan4EU model is going to be used for CS7 analysis, where :
    - Modelling of hydro generation is aggregated (one lake by country/region, no hydro valleys)
    - Modelling of transmission network is simplified (clustering)
- The case study is focused on unlocking flexibility from sector coupling of power and heat sectors, but not from other sectors

3.7.4 Set of models

Table 13. The format of the set of models

Models	Lead Partner	Main Objective
Plan4EU	EDF	To create a 2050 Danish power and heating system scenario
Frigg	DTU	To characterize flexibility provided by the heating sector and calculate the flexibility potential

Table 14. Summary of models requirements

	Geography		**Time**		**Technological scope**
	Horizon	**Granularity**	**Horizon**	**Granularity**	
Plan4EU	National	Sectoral (power and heat)	one year (2050)	hourly	• Power and heat generation technologies
Frigg	National	Sectoral (power and heat)	one year	5-min, hourly	• Heat generation technologies

Model type and problem:

Plan4EU modelling framework

CS7 will use Plan 4EU modelling framework. It will evaluate the flexibility that can be provided by the heat sector in order to reduce the amount of curtailed variable renewable energy sources in the power sector. Plan4EU model will be also used to generate the marginal electricity prices from the system.

Frigg

This model will be used to characterize and calculate the amount of potential flexibility in the heating system that will be fed back to the Plan4EU modelling framework. It will be used both for characterizing the energy flexibility, as well as to establish its potential for the case of Denmark.

Input data

Plan4EU: Input data are transmission grid capacities with the neighbouring countries in MW. Furthermore, solar PV and wind generation profiles, as well as load profiles of different sectors on hourly resolution (MWh/h).

Frigg: Input data from Plan4EU is initial hourly demand data as well as hourly marginal prices in the power and heating sectors.

Output data

Plan4EU: Hourly generation of different plants in MWh/h, hourly CO2 emissions, marginal prices in the power and heat sectors. Marginal prices that is output of the Plan4EU model will be used as an input to the Frigg model.

Frigg: Updated hourly heat and power demand in MWh/h.

3.7.5 Workflow of the case study

This section presents, in a clear and simple manner, the workflow of the case study.

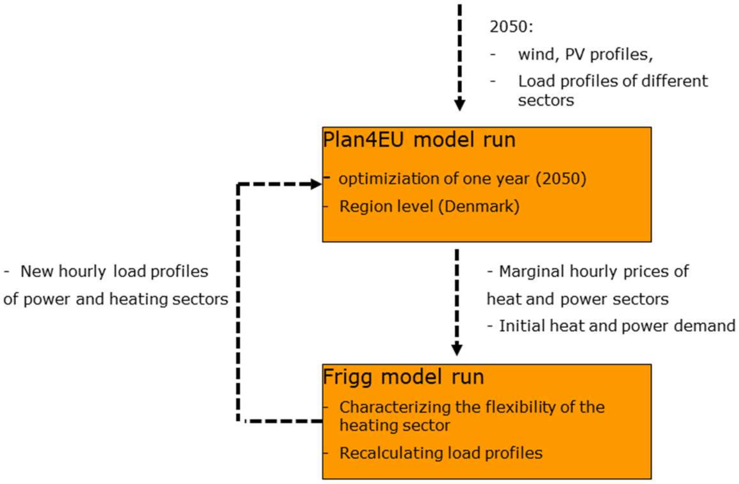


Figure 40 : CS7 general Workflow

3.7.6 General list of data

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Installed capacities per technology in 2050 for the case of Denmark

- Energy demand per country per use in 2050 for the case of Denmark
- Fuel prices and CO2 emission price (or budget)

Data coming from modelling teams own databases

- Available amount of biomass (yearly)
- Demand profiles in different sectors

Data produced during the case study exercise (mainly outputs of models)

This data will be exchanged between models as inputs for someone's and output for others. As examples of it, we have:

- Transmission grid (capacities between nodes)
- Generation profiles for wind, PV, hydro correlated to meteorological time series
- Marginal prices in power and heat sector (hourly)
- Load profiles before and after applied flexibility
- Electricity generation from all variable renewable energy sources before and after applied flexibility

3.7.7 Data workflow

The specificities of the data exchanged among models are presented in this section.

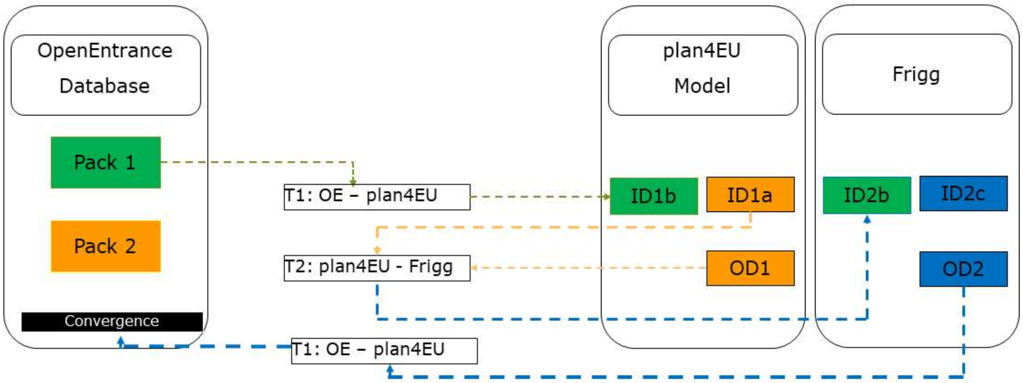


Figure 41 : Data workflow

A list of specific dataPacks

dataPack	Data flow	Content, as example:

Pack 1	Input data from Scenarios, for plan4EU model	Technology operation costs Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data exchanged between plan4EU and Frigg models (output from plan4EU as input for Frigg model)	Generation profiles of different generators Associated costs of heat generation Heat and power demand hourly profiles

List of Datasets (using the models own formats):

ID1a	Input dataset **"part a"** that comes from the own **Plan4EU**'s database
ID1b	Input dataset **"part b"** that comes from the openENTRANCE database to **plan4EU**
ID2b	Input dataset **"part b"** that comes from the plan4EU database to **Frigg model**
OD1	Output dataset from **plan4EU** to openENTRANCE database
ID2c	Input dataset **"part c"** that comes from the **Frigg**'s own database
OD2	Output dataset from **Frigg** to **plan4EU**

3.7.8 Data-exchange tools

A list of the data-exchange tools that need to be implemented to perform the linkage of models and the common data format. An example list is provided below:

T1 (OE-plan4EU)	Set of tools or methods to convert data from the **Common data format** to **plan4EU** format
T2(plan4EU-Frigg)	Set of tools or methods to convert data from the **plan4EU** format to **Frigg** format

3.7.9 Execution order

This section provides the stepwise plan to carry out the case study, specifying the data exchanged (with the relevant data-exchange tools if appropriate). An example is provided below:

Extraction of data from openENTRANCE Database: First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T1** into plan4EU data formats ID1b.

1. **Building plan4EU Input dataset and running plan4EU:** The plan4EU's dataset is built out of plan4EU's own data (**ID1a**) and openENTRANCE Scenario data (**ID1b**). Plan4EU is executed and produces outputs. **OD1** is the part of the output that can be shared, while other part of the outputs will be kept as part of the results that will not continue the workflow or data that has to be kept in private. **OD1** is converted to the **Common data format** using **T4**, which produces **Pack2**.

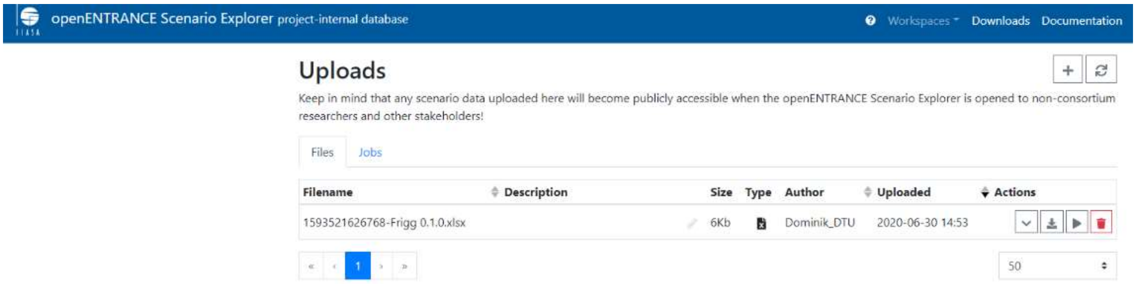
2. **Exchanging between plan4EU and Frigg**: Data from **Pack2** (produced by **plan4EU**) are downloaded and converted to **Frigg** format using **T2** => **ID2b**.

3. **Building Frigg Input dataset and running Frigg:** The Frigg's dataset is built out of Friggs own data (**ID2c**) and plan4EU data (**ID2b, OD1**). Frigg is executed and produces outputs. **OD2** is the part of the outputs that can be shared. **OD2** will be in the **Common data format**.

4. **Updating plan4EU dataset and running plan4EU**: **OD2** data from **Frigg** is used in order to update the **plan4EU** dataset. Plan4EU is running again, which produces the final output.

3.7.10 Implementation in the openENTRANCE scenario Explorer (screenshot)

The upload of the case study results has been successfully tested. Figure 42 presents the upload of the Frigg model to the OpenENTRANCE Scenario Explorer while Figure 43 illustrates the workspace created in the database.

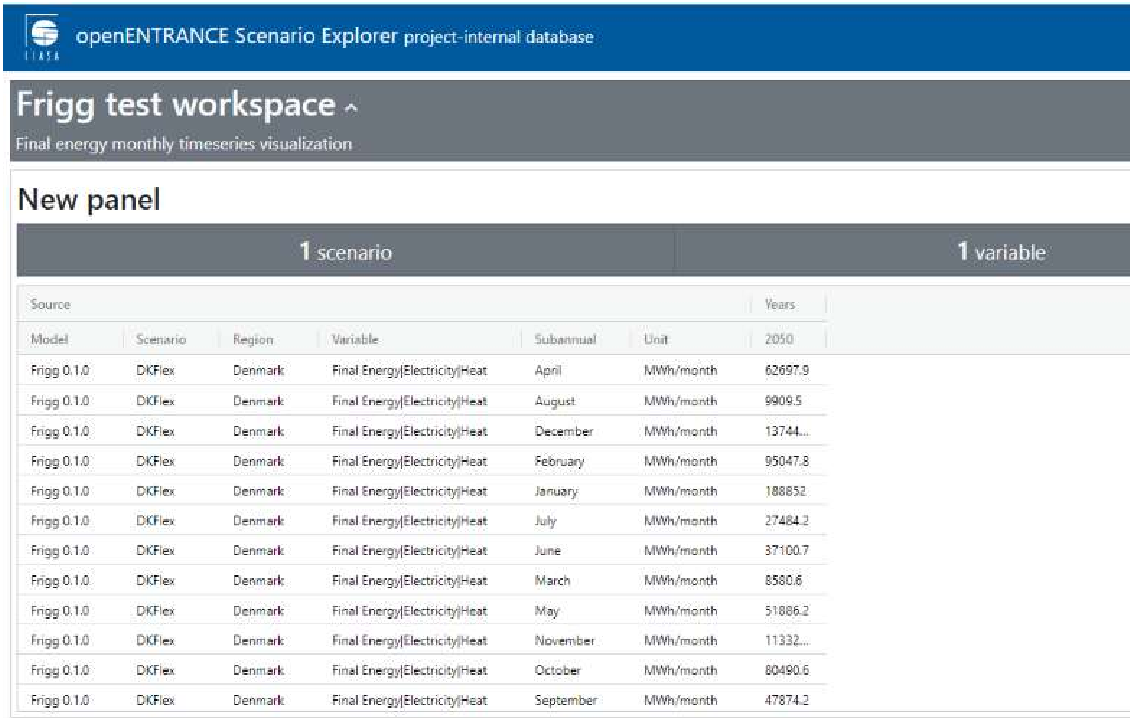


Uploads

Keep in mind that any scenario data uploaded here will become publicly accessible when the openENTRANCE Scenario Explorer is opened to non-consortium researchers and other stakeholders!

Filename	Description	Size	Type	Author	Uploaded	Actions
1593521626768-Frigg 0.1.0.xlsx		6Kb		Dominik_DTU	2020-06-30 14:53	

Figure 42: Test upload of the Frigg model results to the openENTRANCE Scenario Explorer



Frigg test workspace

Final energy monthly timeseries visualization

New panel

1 scenario

1 variable

Source						Years
Model	Scenario	Region	Variable	Subannual	Unit	2050
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	April	MWh/month	62697.9
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	August	MWh/month	9909.5
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	December	MWh/month	13744...
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	February	MWh/month	95047.8
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	January	MWh/month	188852
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	July	MWh/month	27484.2
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	June	MWh/month	37100.7
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	March	MWh/month	8580.6
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	May	MWh/month	51886.2
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	November	MWh/month	11332...
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	October	MWh/month	80490.6
Frigg 0.1.0	DKFlex	Denmark	Final Energy|Electricity|Heat	September	MWh/month	47874.2

Figure 43: A test workspace created from the Frigg output timeseries

3.8 Case Study 8 Need of flexibility – natural gas storage

3.8.1 Case study objective and challenges beyond the state of the art

The impact of a fossil-based energy supply as well as the progressing scarcity of resources have already initiated a transition to a renewable energy system. For economic and technological reasons, this transition is based mainly on photovoltaic cells and wind turbines, both of which are characterized by volatile, weather-dependent power production.

Production of chemical energy carriers using electric power during peak power production periods is termed “power to gas” (PtG). The key technology for this concept is electrolysis, where electric energy is used to split water into hydrogen and oxygen.

The main objective of this case study is to investigate and develop a better understanding of the potential of energy storage through PtG technology, specifically the storage of natural gas obtained from PtG. This case study aims to quantify how PtG can help store energy as natural gas to be used later when needed and how this option can be used with renewables and can reduce the usage of conventional energy sources.

Turkey is located in the middle of Caucasian and Middle Eastern countries, which have more than 75% of natural gas reserves. Although the country imports 95% of its natural gas demand, the objective is to become an energy hub, an energy corridor to Europe, and a market player using the advantage of being on the crossroads of pipeline networks. The deregulation process for the natural gas market is still ongoing with an active daily bidding mechanism.

Storage operations are considered as a requirement for the success of the natural gas market and supply security. Although Turkey's natural gas storage capacity has been increased in recent years, the total capacity is limited to 2.84 Billion Sm^3, which is around 5% of the total demand. Natural gas can be stored in the Silivri, Northern Marmara, Degirmenkoy, and Lake Tuz (Salt Lake) Underground Natural Gas Storage Facilities. The Salt Lake facility has added significant storage capacity of 1.2 Billion Sm^3 as of 2020 and it is planned to reach 5.4 Billion Sm^3 by 2023. In current market conditions, a supplier can apply for storage capacity, and natural gas can be stored, injected, and withdrawn to the national pipeline upon request. Natural gas storage capacity is planned to be around 10% of the total demand by 2023.

In light of Turkey's ambition to be a natural gas market player, PtG can dramatically help the country to expand its capacity once the potential is properly explored. The case study will help identifying drivers as well as barriers to investment into this technology. Given that the country largely imports its natural gas demand, such technology is expected to be an attractive option to increase the overall capacity. The storage capacity has been increased to a significant level and there is a plan to extend it further. The case study will explore the possibility of using the storage capacity and integration with deregulated market operations.

In addition to large-scale long-term storage, power-to-gas facilitates the connection of the power sector to other energy sectors, i.e. heat and fuel supply. Produced H2 can be injected directly into natural gas grid with limited quantity or methanation of the produced H2 with CO2 (called renewable power methane) can be subsequently feed-in into the natural gas grid in unlimited quantities.

Power-to-gas (PtG) converts electricity into hydrogen using the electrolysis process and uses the gas grid for the storage and transport of hydrogen. This method is different from conventional electrical energy storage systems, which absorb and output electrical energy (pumped storage, batteries). PtG systems produce hydrogen that can be blended with natural gas in a quantity and quality compatible with the gas grid.

In this case study, the impacts and benefits of employing PtG systems in the integrated operation of the Turkish electricity and gas networks will be investigated. The study allows the minimum cost of investment in the combined system to determine the electricity generation mix and gas supply dispatched to meet the annual electricity and gas demand.

The optimization model minimizes the total investment cost of the combined gas and electricity system including the costs of gas supplies, gas storage operation, power generation over the entire time horizon while meeting gas and electricity demand. The model will also be used for capacity planning and expansions.

A combined gas and electricity investment model will be developed. The model simultaneously minimizes power investments and the operational cost of gas storage. The developed model will be used to analyse the Turkish gas and electricity expansion requirements to achieve a low carbon energy system.

This case study will investigate the role of natural gas storage in current and future energy systems in transition. Like other case studies, Case Study 8 will also explore a policy recommendation aimed at stimulating the transition to a low-carbon energy system.

Power-to-gas injects a new level of flexibility into the energy supply system through the production of hydrogen and/or methane. Renewable gas from the power-to-gas conversion of surplus renewable electricity can potentially be stored in natural gas storage. For the cases of Germany and Turkey, the processes' costs, and capacities as well as the model and its applications will be analysed.

GENeSYS-MOD will be used in this case study, an energy system model developed over multiple years which builds on the Open Source Energy System OSeMOSYS, GENeSYS-MOD is developed and maintained at TU Berlin. The case study is working closely with TU-Berlin to coordinate our efforts.

3.8.2 Detailed methodology of the case study: modus operandi

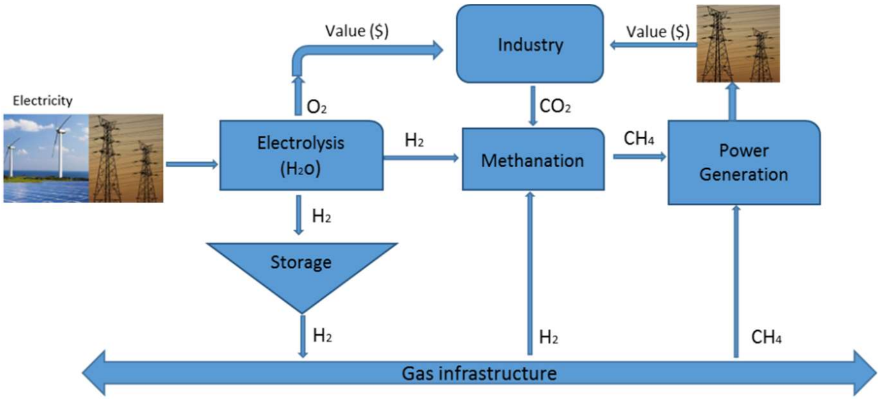


Figure 44: Renewable Power Methane technology

The GENeSYS-MOD-Turkey model (or so-called OSeMOSYS-Turkey) will be used to simulate the impact of natural gas storage in supporting flexibility of the future energy system in transition in Turkey. There are already four installed natural gas storage units in Turkey. They will be used as the starting point and will be adjusted to include renewable power methane storage (Figure 44). This model description will function as the baseline throughout the case study. The analysis will be conducted on the ability of the existing natural gas storage units to supply peak demands of natural gas, especially during winter. This will be followed by a calculation of how much excess electricity (and therefore renewable power methane) that without the natural gas storage units cannot be used, can be stored in the planned natural gas storage units. As one of the important co-benefits of the installation of natural gas storage units, reduction in imports of natural gas is expected. We analyse the cost of importing natural gas in the absence of the natural gas storage units.

As a complementary element of the case study, a cost/benefit analysis will be conducted for the natural gas storage. This will include the economic costs to the state company (i.e. BOTAS) for building the electrolysers and storage units. Moreover, environmental benefits as well as potential climate benefits through the supply chain will be considered and elaborated on.

To better understand what affects investments beyond rational economic reasoning, the key actors in the natural gas sector of Turkey (state company BOTAS, who is responsible for operating the storage units) are intended to be interviewed. A qualitative assessment of the interviews is to yield better insights in the underlying drivers and barriers for investments which are until now not captured in the model.

The model takes parameters such as the demand profiles for heat, electricity and transportation, unit availabilities, existing storage capacities, and efficiency as inputs. As GENeSYS-MOD computes the least-costly combination of technologies to be used to meet energy demand, electricity generation capacities, natural gas storage capacities, natural gas storage, electrolysis capacities, heat and electricity production, primary secondary electricity supply, and emission information will be calculated and provided as outputs for a 30 years time horizon.

Finally, a qualitative discussion of the potential of this novel type of natural gas storage on a pan-European level (for example, Germany) will be conducted. Since the natural gas storage depends on the well-developed natural gas infrastructure, we will have an idea where in Europe this technology could be deployed. Given this insight, the results obtained from the Turkish case can be discussed on the European level to provide a better understanding of the potential importance of PtG technology and storage. Furthermore, we will provide an elaboration on challenges and advantages of this type of storage in comparison to other storage types (e.g., batteries, EVs).

The model will determine the minimum cost of meeting the electricity and gas demand in a daily basis in Turkey in the presence of a significant capacity of renewable energy generation. Electrolysis facilities will be located where there is significant amount of generation from renewable energy sources. The impacts and benefits of employing PtG systems in the integrated operation of the Turkish electricity and gas networks will be investigated. The study allows minimum cost of operation in the combined system to determine the electricity generation mix and gas supply dispatched to meet the daily electricity and gas demand.

The total cost of electricity generation and gas supply will be minimized. The cost of gas supply includes gas supply from the storage facilities. Gas supply from terminals, storage facilities, and renewable methane produced by electrolysers has to be equal to the gas consumption.

The amount of hydrogen production and the electrolyser efficiency determine the electricity demand for renewable power methane. Gas terminals and storage facilities are included in the model. Investments in PtG capacity are calculated by the model.

In summary, GENeSYS-MOD-Turkey model takes inputs from openENTRANCE's scenario explorer (i.e. power and heat investments, costs of technologies and fuels) as well as inputs from KHAS' own database (i.e. cost of electrolysis, obtaining renewable power methane, and maximum natural gas storage level) which are used to define the natural gas storage capacities. Then the model is expected to perform a least cost power, heat, and gas operation planning considering hourly time increments for a 30-years time horizon. The outputs are the required electrolyser and natural gas storage investments for the sustainability, reliability and cost effectiveness of the electricity and gas system.

3.8.3 Expected results and limitations

This case study is to yield quantitative results as well as qualitative insights on the impacts of natural gas storage units on the Turkish energy system. The results can be categorized into general and specific:

General results

General results can be summarized as:

- A better understanding of the possibility and related impacts of the use of natural gas storage in Turkey and suitable locations across Europe
- A better understanding of drivers and limitations/barriers of investments in natural gas storage units

The GENeSYS-MOD model is a full-fledged energy system originally based on the open-source energy modelling system, called OSeMOSYS. The model uses a system of linear equations of the energy system to search for lowest-cost solutions for a secure energy supply, given externally defined constraints on greenhouse-gas (GHG) emissions. It takes into account increasing interdependencies between traditionally segregated sectors, e.g., electricity, transportation, and heating. OSeMOSYS itself is used in a variety of research to provide insights about regional energy systems and their transition towards renewable energies. Initial model, written in GNU MathProg (GMPL), was translated into the widely used and available GAMS software. The team at TU Berlin extended the code and implemented additional functionalities, e.g., a modal split for the transportation sector or relative investment limits for the single model periods. Both the code and the data used by GENeSYS-MOD are open-access and freely available to the scientific community. More details for GENeSYS-MOD are provided in Chapter 2 of this report.

Introducing a PtG system in the model will increase the ability of the power-to-gas system to use electricity producing hydrogen at locations where renewable energy generation was curtailed. The operating cost of the combined system will be reduced. Renewable power methane injection into the gas system is expected to lower the total emissions. This will partially decarbonize the system by injecting renewable power methane.

Turkey imports a significant share of its natural gas supply and there are efforts to increase the storage capacity. The country is located on the cross-roads of pipelines and seeks to utilize this advantage. The PtG facilities and gas storage has the potential to support the country's vision to reach a reliable natural gas market and to be a significant market player through forming an energy hub. Increasing investments in PtG facilities is expected to decrease the import needs or at least does not increase the imports against peak demand. On the other hand, for a system with limited natural gas storage capacity, it will be crucial to assess the feasibility of PtG facilities and new-build gas storage for the low-carbon energy transition.

The country is a neighbour country to Europe, has an interconnected electricity system, and natural gas pipelines connected to Europe. Increasing PtG and storage capacity will provide benefits to both Turkey and Europe as there is an opportunity for sharing experience and knowledge as well as an opportunity for integration, reliability, and efficiency.

Specific results

More specifically, the case study will provide several indicators for defined time increments and planning horizon such as electricity generation capacities, natural gas storage capacities, electrolysis capacities, heat and electricity production, primary and secondary electricity supply, and emission mitigation in order to reach the target levels which are given as inputs. The inputs include parameters such as the demand profiles for heat, electricity and transportation, unit availabilities, existing storage capacities, and efficiencies. It is also possible to investigate the variability of those indicators by simulating the operation decisions on several scenario of uncertainties.

Quantitative results include:

- The estimated, potential reduction of unused renewable electricity generation through the use of natural gas storage.
- The capacity of such a storage unit to supply peak demand of natural gas during winter.
- The reduction in import expenditure compared to a case without natural gas storage.
- A cost/benefit analysis for PtG technology and natural gas storage.

Electrolysers will be mostly operated when the electricity demand is low and renewable generation is high. In other words, at times of low demand, electrolysers will work to support the gas storage system. The utilization of hydrogen electrolysers leads to a fraction of the gas demand to be met through the hydrogen produced from electricity, and therefore reduces gas flow from terminals and subsequently decreases gas consumption.

The excess renewable energy is used for the process and renewable energy resources are utilized while fossil fuel usage is decreased. On the other hand, the cost of operating electrolysers should be covered when the gas is used to generate electricity to be sold to the market. Such system can be considered as a typical example of large-scale electricity storage system in which a form of energy is transformed into another form and stored to be used when the prices are viable or peak consumption is expected.

Limitations

The main assumption of the PtG system to be used in this study will be that CO2 is available and can be readily mixed with H2 from electrolysis to obtain renewable power methane. Limited amount of H2 can be injected to natural gas grid, but this option will not be considered in this study as we do not know its effect on the pipelines and storage infrastructure.

Detailed energy data for Turkey is available in KHAS-OSeMOSYS model, but the injection and withdrawal capacities of the natural gas storage is not available, hence it will be based on expert estimations. Also, we need to carefully add the locations of natural gas storage to the model, since we omit the cost of transportation between PtG facilities on renewable energy sites and natural gas storage locations.

Another limitation within the assessment in CS8 is that the total natural gas storage capacity is a user-defined input to the GENeSYS-MOD-Turkey. This means that the size of the storage is predefined and hence cannot be optimized. This is a key limitation to the available module, since a good understanding of PtG is necessary to ensure sensible input arguments for charge/discharge amounts of natural gas. This poses a limitation since it is not always given that the modeller is sufficiently familiar with the characteristics of PtG and production of renewable power methane. Other potential limitations are:

- Gas transmission network of Turkey will not be added in the analysis, due to non-convex nature of the gas flow constraints.
- The natural gas storage service is provided for a cost, the details of the cost, whether it is linear or nonlinear, is not known. We will resort our attention to linear costs in this case study.

3.8.4 Set of models

Table 15. Sample of format the set of models

Models	Lead Partner	Main Objective
GENeSYS-MOD	TU-Berlin	Generation expansion under various scenarios. Cost minimization for operation and investments in energy systems. Power, heat, and transportation sectors are included

GENeSYS-MOD-Turkey	KHAS	Generation expansion under various scenarios. Cost minimization for operation and investments in energy systems. Power, heat and transportation sectors are included. Natural gas storage is included.

Table 16. Sample of format for the summary of model requirements

	Geography		**Time**		**Technological scope**
	Horizon	**Granularity**	**Horizon**	**Granularity**	
GENeSYS-MOD	EU27+NOR/CH/UK/TR/Balkan-Region	Country level	Typically, 1 hour for operational model and 20-50 years for investment analysis	Hourly	• Natural gas storage • Electricity • Heat • Transportation
GENeSYS-MOD-Turkey	Turkey	Country, regional level	Typically, 1 hour for operational model and 20-50 years for investment analysis	Hourly	• Natural gas storage • Electricity • Heat • Transportation • PtG

Model type and problem:

The modelling will investigate the potential for gas storage and PtG to provide additional flexibility to the energy system. The level of the time resolution in the energy model will be high in order to capture the effects of intermittent renewable energy supply and demand peaks. The OSeMOSYS-based energy system model GENeSYS-MOD will be used in this case study. A European version of the GAMS-programmed OSeMOSYS-model, GENeSYS-MOD, is developed and maintained at TU Berlin. PtG functionality will be added into GENeSYS-MOD-Turkey (KHAS, linked) and GENeSYS-MOD-Germany (linked) will be compared. Depending on the costs and capacities of power-to-gas facilities and gas storage, natural gas storage will play a more or less strong role. For energy systems without much natural gas storage yet, considering the low-carbon energy transition will be crucial for a sound assessment of the economic viability of new–built gas storage. Although there is still limited gas storage capacity in Turkey, there are efforts to increase the storage capacity and open this capacity usage to market players. The modelling will allow more market participants to assess the feasibility of PtG given that more gas can be stored at a reasonable cost and the stored gas will be withdrawn when it is economic.

GENeSYS-Mod-Turkey is a tool for energy system planning:

- Multiple energy carriers
- Optimizes hourly operation and future investments (type, time)
- Minimizes total energy system costs

- Models a country and its regions
- Models a full year through time slices
- Each day is modelled at an hourly resolution
- Considers energy needs as well as peak loads
- Different sub-modules for different technologies
- New technology can be incorporated to assess its impact on the existing energy system demands
- Timeframe: long term planning horizon
- General technical constraints
    - Hourly resolution for optimization
    - Representative time slots to model a full year
- Specific constraints to each technology module

Storage-module

- The storage is supplied with natural gas through a supply point
- The storage supplies natural gas to natural gas grid
- The storage can either be charged or discharged
- 24-hour time horizon

Input data

Model	**Variable**	**Description**	**Unit**	**Spatial**		**Temporal**	
				Granularity	**Flexibility**	**Granularity**	**Flexibility**
GENeSYS-MOD-Turkey	Electricity Demand	Electricity demand profile	MWh	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Heat Demand	Heat demand profile	bcm	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Transportation Demand	Transportation Demand Profile	tpe	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Initial natural gas storage capacity	Maximum state of charge of each storage	bcm	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Initial PtG capacity	Maximum (dis)charging power of each storage unit	MW	Storage node	Storage node	Hourly	**From:** yearly **Until:** hourly

GENeSYS-MOD-Turkey	Availability	Availability of generation units, power to gas electrolizers	-	Generation unit	Generation unit	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Efficiency	Efficiency of generation units, power to gas electrolizers	-	Generation unit	Generation unit	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Natural Gas supply	Amount of natural gas supply to gas grid	bcm	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly

Output data

Model	**Variable**	**Description**	**Unit**	**Spatial**		**Temporal**	
				Granularity	**Flexibility**	**Granularity**	**Flexibility**
GENeSYS-MOD-Turkey	Natural gas storage amount	Natural gas storage from renewable power methane	bcm/hour	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Natural gas storage capacity	Storage capacity investments	bcm	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Electricity generation capacity	Generation capacity investments	GW	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Electrolysis (PtG) transformation capacity	Electrolysis investments	GW	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Heat and electricity production	Production by fuels	EJ/hour	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly
GENeSYS-MOD-Turkey	Primary/secondary energy supply	Supply by fuels	EJ/hour	Regional node	Regional node	Hourly	**From:** yearly **Until:** hourly

GENeSYS-MOD-Turkey	Emissions by each sector	Emissions by each demand and supply sector	Mt CO2/year	Regional node	Regional node	Yearly	**From:** yearly **Until:** hourly

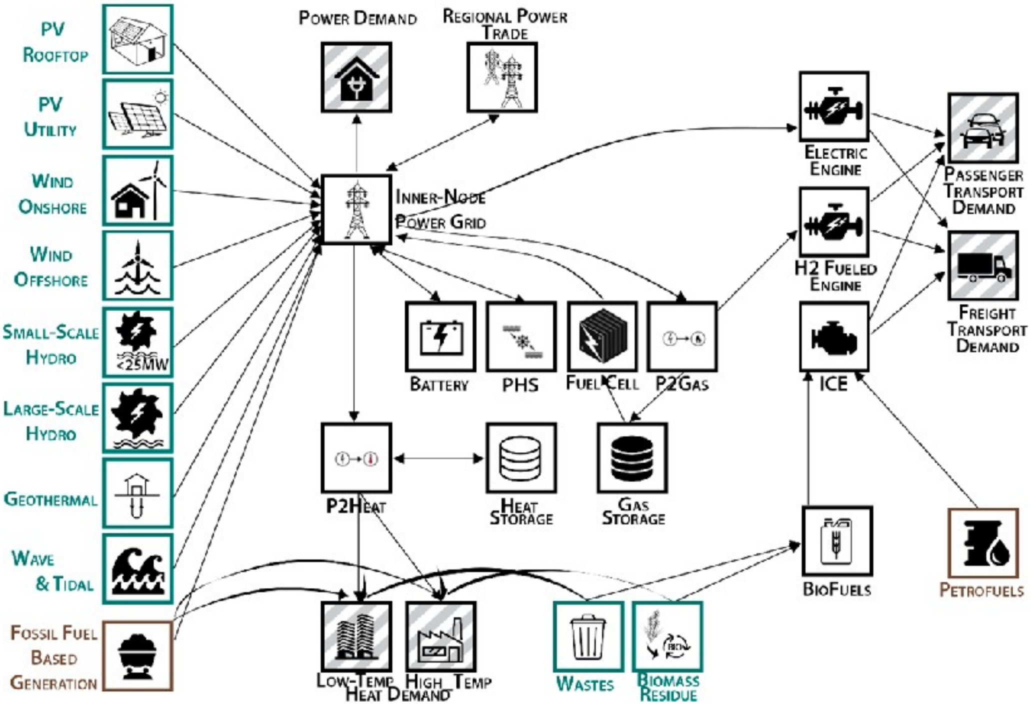


Figure 45: Schematic overview of GENeSYS-MOD[30] developed at TU Berlin

3.8.5 Workflow of the case study

This section presents, clearly and simply, the workflow of the case study.

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[30] https://openenergy-platform.org/factsheets/frameworks/73/

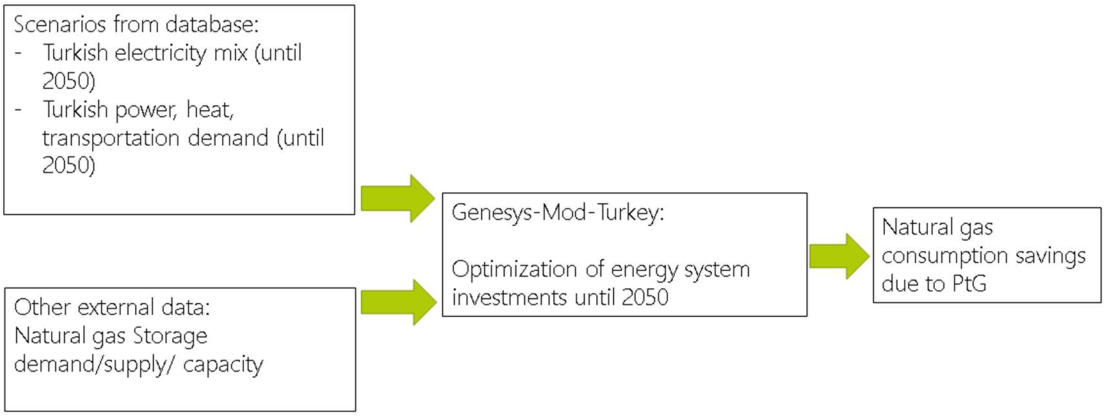


Figure 46 : Case study 8 general workflow

3.8.6 General list of data

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Electricity mix of Turkey (scenario work – until 2050)
- Energy demand in Turkey per use until 2050
- Electricity and natural gas prices
    - Average retail electricity price for customers
    - Average day-ahead spot market prices
    - Average natural gas price
- Emission produced in the electricity system
    - Marginal emissions
- Investments into electricity generation and supply

Data coming from modelling teams' own databases

- Natural gas storage/transmission and distribution capacity
- Electricity and natural gas demand in the modelled area
- Electricity and natural gas supply in the modelled area
- Power-to-gas technologies
    - Maximum capacities
    - Maximum (dis)charging power
    - Efficiency factor
    - Costs
- Hourly generation profiles, hourly load profiles, hourly generation from each energy source
- Energy import/export data
- Transportation data
- Installed capacities and generation/production mix per technology and sector
- Electrolyser and CO2 capital and operation costs

Data produced during the case study exercise (mainly outputs of models)

- Natural gas consumption at each regional node
- Amount of flexibility added by the renewable power methane obtained from electrolysis
- NPV analyses
- GHG-emissions
- Natural gas obtained from local renewable resources
- Potential natural gas import savings from PtG expansion

3.8.7 Data workflow

In this case study, the focus is on investigating the potential of the PtG in obtaining renewable power methane to be used in natural gas storage. There will only be used one model, the GENeSYS-Mod-Turkey model and hence no data will be exchanged between models. However, scenario data from the openENTRANCE scenario explorer will be used. (see Figure 47).

The figure illustrates:

- The openENTRANCE database provides scenario information.
- There is only one model used and it receives data from the open database and from external sources
- There is one tool converting the data from the Common Data format of the Database to the input data format of the model (**T1**)
- Dashed lines represent the flow of information

It is considered 2 types of dataPacks:

1. Whose content comes from openENTRANCE scenarios (**Pack1**)
2. Whose content comes from model's own database **(Pack 2)**

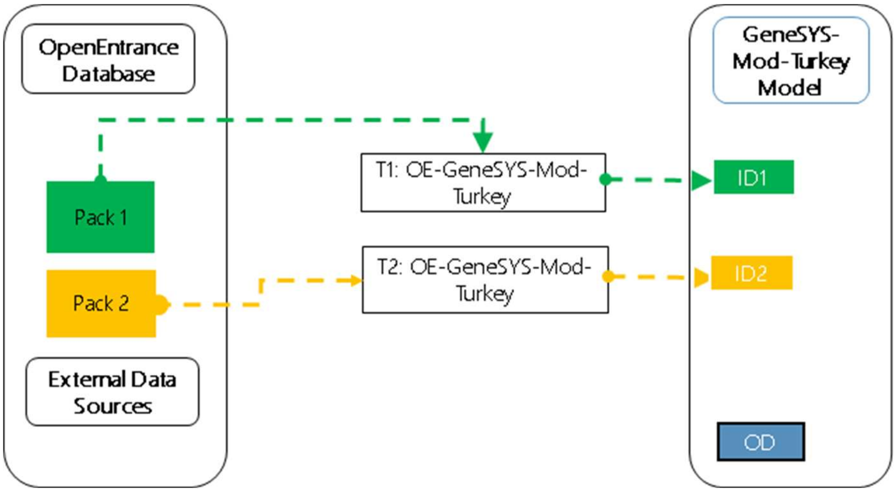


Figure 47: Data workflow

dataPack	Data flow	Content, as example:
Pack 1	Input data from Scenarios, common among models	Technology operation costs Energy demand per uses (power, heat, cooling, industry, transport) Installed capacities
Pack 2	Data from external sources	Generation profiles for wind, PV, hydro correlated to meteorological time series Other generation profiles (biomass for example) Electricity Demand profiles correlated to temperature time series (including electric vehicle profile) Power technologies with their financial and technical parameters Electrolysis and Storage technologies Regional distribution capacities (heat and electricity)

List of Datasets (using the models' own formats):

ID1	**Input dataset "1" that comes from the openENTRANCE database to GENeSYS-MOD-Turkey, *i.e. energy demand and Turkish/European energy mix, etc.***
ID2	Input dataset **"2"** that comes from external data sources to **GENeSYS-MOD-Turkey**, *i.e. Electricity demand*
OD	Output dataset from **GENeSYS-MOD-Turkey to openENTRANCE database**, *i.e. optimal PtG investments*

3.8.8 Data-exchange tools

Two data-exchange tools need to be implemented to perform the linkage of data from the OE platform and external sources to the GENeSYS-MOD-Turkey model. These tools (or translators) will include:

T1 (OE-Model 1)	**Set of tools or methods to convert data from the Common data format to GENeSYS-MOD format**
T2 (ext.-Model 1)	Set of tools or methods to convert **external data formats** to GENeSYS-MOD **formats**

3.8.9 Execution order

This section provides a stepwise plan to carry out the case study, specifying the data and the relevant data-exchange tools:

1. **Extraction of data from openENTRANCE Database:** First, the **Pack 1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is transformed through **T1** into **GENeSYS-MOD-Turkey** data formats **ID1**.
2. **Building OSeMOSYS-Turkey's input dataset and running OSeMOSYS-Turkey:** The GENeSYS-MOD-Turkey indata dataset is built out of data from external sources (which are converted to the eTransport dataformat trough **T2**) to a dataset in the right input format (**ID1**) and openENTRANCE Scenario data (**ID2**). GENeSYS-MOD-

Turkey is executed and produces outputs **OD.** The output will not be shared on the open platform and is analysed and used only in this particular case study.

3.8.10 Implementation in the openENTRANCE scenario Explorer (screenshot)

As of now (time of writing this deliverable), there is no data or results from this case study in the openENTRANCE scenario explorer. However, the GENeSYS-MOD results regarding the openENTRANCE scenarios is available, see Figure 48 for an example.

This workspace shows the development of the primary-energy mix and total CO2 emissions in the pathway quantifications using GENeSYS-MOD as reported in Deliverable 3.1

Figure 48: Example of GENESYSMOD workspace in the openENTRANCE scenario explorer

3.9. Case Study 9 – Effective policies for investment incentives

3.9.1 Overall objective and case-study baseline

Achieving a large share of renewables in the energy system requires incentives and new market-regulatory frameworks to support different actors to invest in the energy transition. Understanding the impact that different shocks exert on different sectors of the economy is an important step to evaluate the effectiveness of energy policies. Nevertheless, the implementation of such policies requires a clear representation of regulatory barriers. Important considerations need to be made concerning the market design which will set the rules for the operations of capacity markets, the regulation of cross-border trades in presence of RES and the impact of different policies on the distribution of welfare among the considered Countries. It is important to define the possible barriers that might hinder the correct pathway for fostering a green transition and analyse if and how those barriers can be removed or which measures need to be undertaken to relax and milden their effects.

While the expansion of the technology mix can be effectively determined using a long term energy system expansion model, the effects on the economy of the implemented policies might be overlooked. Nevertheless, these measures can have a profound impact on the economic system, with consequences that are expected to create ripple effects on several sectors. This chain reaction would reverberate on the demand of electricity, which would lead to the need of revising the long run energy system expansion decisions. This motivates the definition of an interface between long term energy system planning models and macroeconomic general equilibrium models to cross validate the effects that energy system and socio-economic system have on each other. For this scope we will link the EMPIRE long term energy expansion model, developed at the department for Industrial Economics and Technology Management and the REMES:EU computable general equilibrium model, developed by the department in partnership with SINTEF. The models operate considering yearly time periods and a European geographical scope. The interplay between the two models on the different structure of the energy production sectors and its consequences in terms of costs and impact on demand can provide an increased level of coherence for the definition of policies which could be extreme enough to provoke a shock on the European economic system in the long run, and therefore must be addressed altogether in an integrated framework.

In this respect, Case Study 9 will consider the analysis of the economic impacts of different policies to foster the integration of Renewable Energy Sources, including the role of subsidies and taxes and the investigation of regulatory barriers. This will be done considering the monetary flows featured in nowadays economy and simulating how these flows are reallocated after the introduction of a policy. The mapping of the shocks to include in the models depend on each model peculiarities. For some of the policies, the best entry point might be REMES, which explicitly models the change in demand for different groups of commodities, with EMPIRE receiving the electricity demand from REMES and passing back the updated technology mix; other policies are best modelled using EMPIRE as an entry point, which provides REMES with the initial technology mix and receives the correspondent demand. In this case the only shock in REMES is the one provided by EMPIRE, while EMPIRE models both the user defined shock and the iterative responses of REMES.
More in detail, we establish the goal of analysing different policies to study

- The design of capacity markets under a high RES scenario,
- The evolution of cross-border trade regulation for the efficient deployment of RES,
- The evolution of electricity pricing schemes in European countries, incl. network charges, locational prices etc. for an effective deployment of RES,
- The role of subsidies, taxes and distributional welfare effects in investment decisions,

These analyses will be used to identify the regulatory barriers for effective investments in the energy transition. The full European technology mix will be represented by the EMPIRE model which has a 'copper plate' representation of the European power network along with long-term capacity expansion decisions. EMPIRE covers all the technological features of a power system model. Then, to perform a more in-depth analysis of the effects of the energy transition in the overall economy, this case study uses the REMES model.

3.9.2 Challenges and beyond the stat of the art

Linking Bottom-up energy system models with Top-down macroeconomic models is not a new trend. It has been carried out in different studies. Nevertheless, the linking process can be quite subtle and does not always lend itself to convergence. Moreover, there is no clear established methodology to establish a linking between two models which might have quite different starting points in terms of data evaluation. Therefore, one of the main challenges will be finding a suitable methodology to obtain a fruitful exchange of information between the models whether a full convergence takes place or not. A key state-of-the-art accomplishment will be the development of a full-fledged European scale bottom-up to top-down energy model. Moreover, some of the planned analyses such as the design of capacity markets have never been performed using a combined energy and socio-economic approach. These analysis push forward the utilization of a combined approach towards previously unexplored areas.

3.9.3 Expected results and limitations

As a general level of analysis we expect the modelling framework to provide insights on the allocation of investments into different energy generation technologies, as well as its economic impacts on the other sectors as a consequence of the different adopted policies. More specifically, for the first sets of analyses we expect the capacity markets to redefine the different Countries as nodes of a large virtual power network where, depending on the availability of natural and technological resources, it will be possible to contribute on a large scale on the generation and delivery of a stable energy supply. The second sets of analyses will shed light on the effects of policies aiming at the reduction of power transmission from Countries employing large share of fossil fuels and the technical and economic effects on the other countries as well as possible carbon leakage effects. The third set of analyses is expected to trigger different responses by the bottom up model into the top down economic model in terms of technology mix, which, will impact differently on the economies. The last set of analyses will provide insights on how the Countries can participate in the investments to drive the green transition.

3.9.4 Detailed methodology of the case study

The case study will consider the different developments over time of the technology mix and the electricity price as a result of the application of different barriers to the penetration of RES into the energy system over time. More in detail the provided output will be covering two dimensions, using a country level granularization and consider the European continent.

- An energy system dimension modelled using the Bottom-Up EMPIRE model will provide decarbonization strategies and changes over time on the overall technology mix. That is, EMPIRE will estimate the necessary technology to accomplish a given CO2 target. It determines endogenous investment decisions on generation and transmission expansion. It also provides hourly profiles on supply-demand operations per country;
- A socio-economic dimension, modelled using the Top-Down REMES:EU model will provide information on GDP development, unemployment rate, sectoral value added, price variations per commodity, allocation of energy consumption per sector and final utilisation and reallocation of the investments as a consequence of the implemented policies.

The results pertaining to the different dimension will be compared under the considered analyses to provide a classification of the most impactful barriers and measures (absence of capacity markets, regulations limiting cross border trade, subsidy schemes).

The two models will be initialized to the handling of common policies and will include common assumptions for the future technical and socio-economic development. A necessary assumption homogenization phase is to be considered prior to establish the linking. This means that an initial storyline will be mapped to shocks that both models can understand and handle. The mapping needs to be transparent and shared between the modellers in order to enhance mutual comprehension of the initial state. EMPIRE will run first using standard assumptions on electricity demand growth. The results will be collected in the openENTRANCE template and be passed on to REMES:EU, which will read them and use these technology structures to map the technological change over time of the power sectors. Thus, REMES_EU will proceed computing a new economic equilibrium over the considered years and produce an output with the development (in percentage) of the electricity demand over the years and the CO2 price. This information will be collected in the IAMC openENTRANCE template and fed back to EMPIRE, which will apply the demand percentage change on its value on the base year to reconstruct the electricity demand over the modelling horizon. The models will proceed exchanging information in this manner until reaching a convergence. We claim the convergence to be satisfied when the norm of the percentage difference in output to be delivered from one model to another is smaller than a predetermined threshold.

3.9.5 Set of Models

The models involved in the development of the case study are the EMPIRE long term energy expansion planning model and the REMES:EU computable general equilibrium model. EMPIRE has been developed at the Industrial Economics and Technology Management department, NTNU. It is a multi-horizon stochastic model capable of integrating long term decisions related to the energy system expansion with the short-term uncertain behaviour of renewable energy sources and provide a plan that takes into account the contribution of those sources into the system. The REMES:EU model is a regional computable equilibrium model with focus on the energy system. It has been developed at SINTEF in partnership with the department of Industrial Economics and Technology Management, at NTNU.

Table 17. Sample of set of models

Models	Lead Partner	Main Objective
REMES	NTNU	To study the effects of macroeconomic policies on the EU economy.
EMPIRE	NTNU	To optimize least-cost energy system configuration and operation

Table 18. Sample of format for the summary of models requirements

	Geography		Time		Technological scope
	Horizon	**Granularity**	**Horizon**	**Granularity**	
REMES	EU27+NOR/CH	Country	year (2050)	Yearly	• Thermal Power Generation • Renewable Power Generation • Hydrogen
EMPIRE	EU27+NOR/CH	Country	year (2050)	Yearly	•

Model type and problem:

The case study will consider the analysis of the economic impacts of different policies to foster the integration of Renewable Energy Sources, including the role of subsidies and taxes and the investigation of regulatory barriers. This will be done using the coordinated effort of the REMES:EU top down CGE model, defining the development of the demand of electricity and the EMPIRE bottom up energy system model, defining the development of the technology mix.

- **REMES:EU**: Equilibrium model for defining the development of the macroeconomic system in each European country.
    - Considers the price for CO2 emission allowances
    - Considers the unemployment rate in each country
- **EMPIRE**: Long term energy system capacity expansion model with Pan-European scale.
    - Detailed handling of short-term behaviour of RES.
    - Considers short-term uncertainty.

The EMPIRE model provides decarbonization strategies and changes over time on the overall technology mix. That is, EMPIRE estimates the necessary technology to accomplish a given CO2 target. It determines endogenous investment decisions on generation and transmission expansion. It also provides hourly profiles on supply-demand operations per country.

The main data requirements for this case study are scenarios for:

- Economic shocks: The taxes and subsidies as well as carbon budget for each considered period.
- Generation mix: new sectoral structure for power generation, as well as percentage of energy coming from dispatchable generation over total generation

- Network topology: Current network topology for intra-European power transmission
- Capacity: Current generation and transmission capacity in the European power grid.

Input data

The following data input is necessary for the top-down and bottom-up models involved in the analyses:

Model	**Variable**	**Description**	**Unit**	**Spatial resolution**	**Temporal resolution**	**Flexibility**
REMES:EU	Social Accounting Matrix	A matrix containing the monetary exchanges between different sectors, commodities and actors in a given year	Million Euros	Country	Year	Possibility to aggregate countries. Disaggregation is not possible without a new dataset
REMES:EU	Trade Matrix	A matrix containing the monetary flows for the international trade of each commodity	Million Euros	International	Year	Possibility to aggregate countries. Disaggregation is not possible without a new dataset
REMES:EU	Elasticities of substitution and transformation	Parameters defining the degree of substitutability between different commodities.	Adimensional quantity	Country	Year	No. They need to be reassessed completely.
REMES:EU	Policies (Taxes, subsidies, CO2 budget, capacity limits etc…)	Mapping of policies into numbers that the CGE can process	Usually monetary or a percentage rate.	Country	Year	Yes.
REMES:EU	Costs to produce one unit output for new sectors	If new sectors are introduced there is need to determine the costs of each input to produce one unit of output	Euros	Country	Irrespective of period.	Yes
REMES:EU	Unit revenue for new products	If new sectors are introduced there is need to determine the unit revenue for each of the output products	Euros	Country	Irrespective of period	Yes
REMES:EU	From bottom up model:	Percentage expenditure on each fuel in the energy	Percentage	Country	Year	Yes

	Technology mix	sector wrt the total expenditure in fuels (or any other desired sector)				
EMPIRE	Demand projections 2020-2050 for all EU countrie	Demand in GWh	GWh	Country	Year	No
EMPIRE	Energy technology CAPEX and OPEX	Costs for generation and expansion in GWh	€/GWh	Country	Year	No
EMPIRE	Technologies efficiency and conversion	Conversion coefficients between commodities	-	Country	Year	No

Output data

Model	Variable	Description	Unit	Spatial resolution	Temporal resolution	Flexibility to change resolution
REMES:EU	Energy Consumption	Amount of energy purchased by each sector and final consumption	Multiplier over total consumption in base year	Country	Year	Can be aggregated.
REMES:EU	Energy price	-	Percentage of the base year.	Country	Year	No
REMES:EU	Price for fuels	-	Percentage of the base year.	Country	Year	No
REMES:EU	CO2 price	-	Percentage of the base year.	Country	Year	No
REMES:EU	GDP	Real GDP per country in the analysed years	Million Euros	Country	Year	Depends on the availability of sub-annual SAMs
REMES:EU	Unemployment	Percentage level of unemployment in each country	Percentage of the total labour force	Country	Year	Depends on the availability of sub-annual SAMs
EMPIRE	Generation Capacity Investments	Investments in each production technology	Million Euros	Country	Year	No
EMPIRE	Generation	Generation profiles for each technology	GWh	Country	Year	No

EMPIRE	Transmission Capacity Investments	Investments in transmission capacity between countries	GWh	Country	Year	No

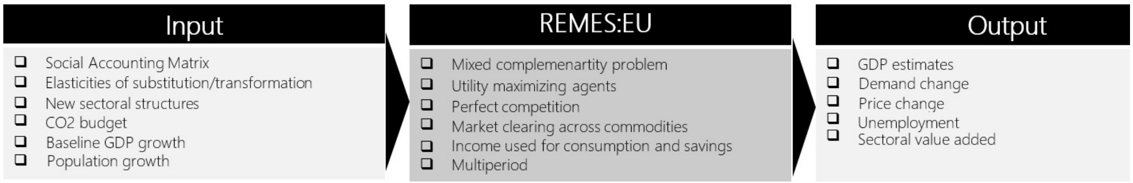


Figure 49: Schematic overview of the REMES:EU model, developed at SINTEF and NTNU

Figure 50 : Schematic overview of the EMPIRE model, developed at NTNU

3.9.6 Workflow of the case study

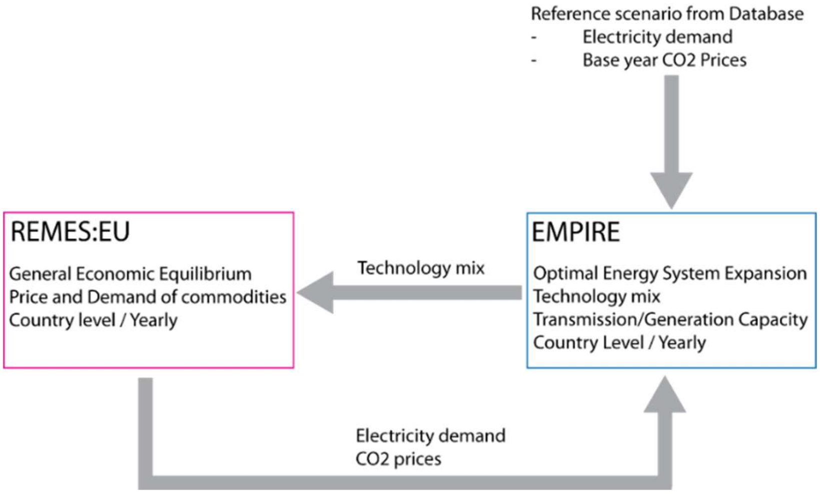


Figure 51 : CS9 high-level Workflow

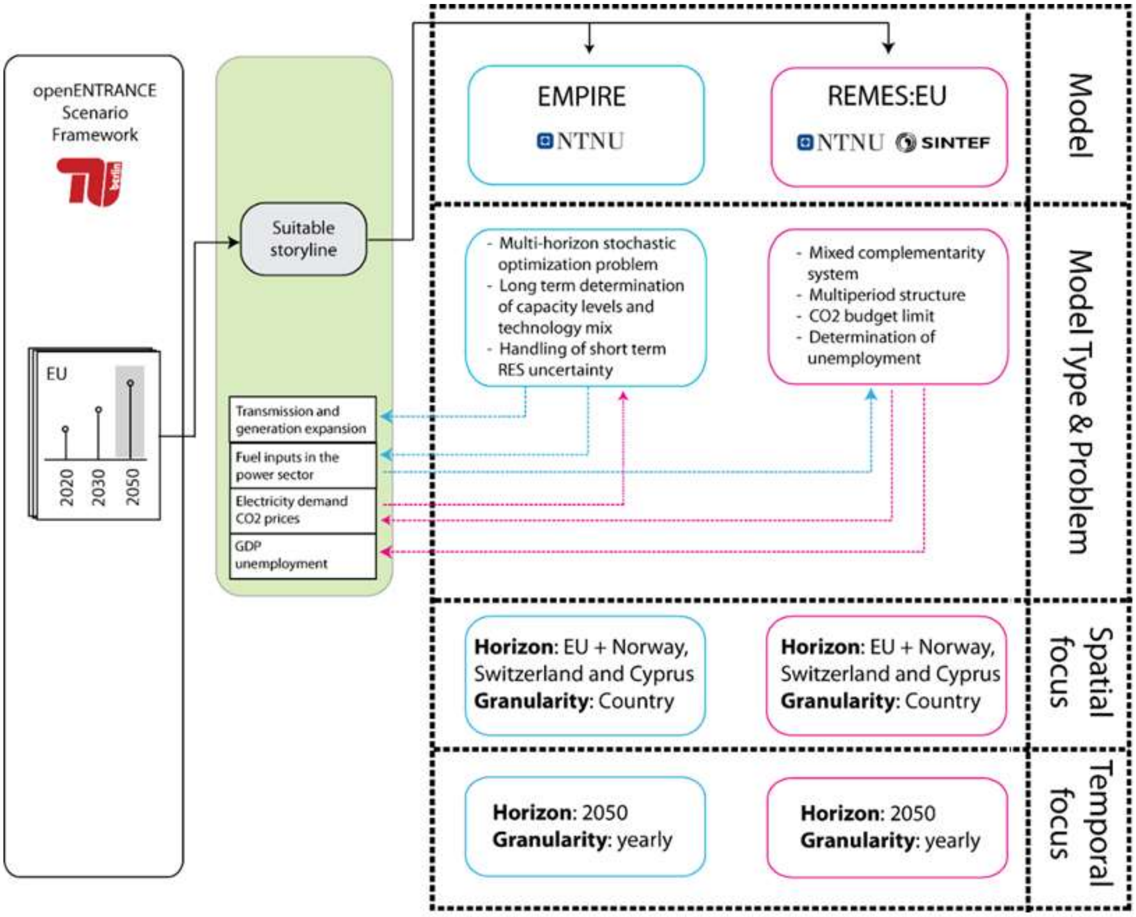


Figure 52: A Schematic overview of the case study 9 (methodology and model linkage).

3.9.7 General list of data

Data coming from openENTRANCE scenarios (for the chosen scenario)

- Installed capacities per country per technology in 2020
- Net electricity production from all sources of solar energy (e.g., solar PV and concentrating solar power)
- Investments into electricity generation and supply (including electricity storage and transmission & distribution)
- Fuel prices, CO2 prices in 2020 and CO2 emission budget over time
- Baseline energy demand projections

Data coming from modelling teams own databases :

- Power technologies with their financial and technical parameters
- Storage technologies
- Hydro technologies with their technical parameters (lakes, run of river, pumped storage)
- Population growth
- Current unemployment level
- Baseline GDP growth

Data produced during the case study exercise (mainly outputs of models)

This data will be exchanged between models as inputs for someone and output for others. As examples of it, we have:

- Yearly electricity demand
- CO2 price
- Technological mix, defined as percentage impact of the fuel source for each unit output.

3.9.8 Data workflow

The specificities of the data exchanged among models are presented in this section. To illustrate the details of the workflow in a general and specific way, we use the example in Figure 53.

Facts that are illustrated in the figure:

- The openENTRANCE database provides scenario information.
- There are two models that receive information from the database and outside the database
- IIASA has made available tools to convert data that comes from each model to the database and vice versa.
- Dashed lines represent the flow of information

Three types of dataPacks are considered:

- Whose content comes from openENTRANCE scenarios (**Pack1**)
- Whose content comes from mode’s own database (not shown in the diagram)
- Whose content comes from models’ output (Pack2, Pack3) and is used as input for other models
- Other example with also data coming from model’s databases

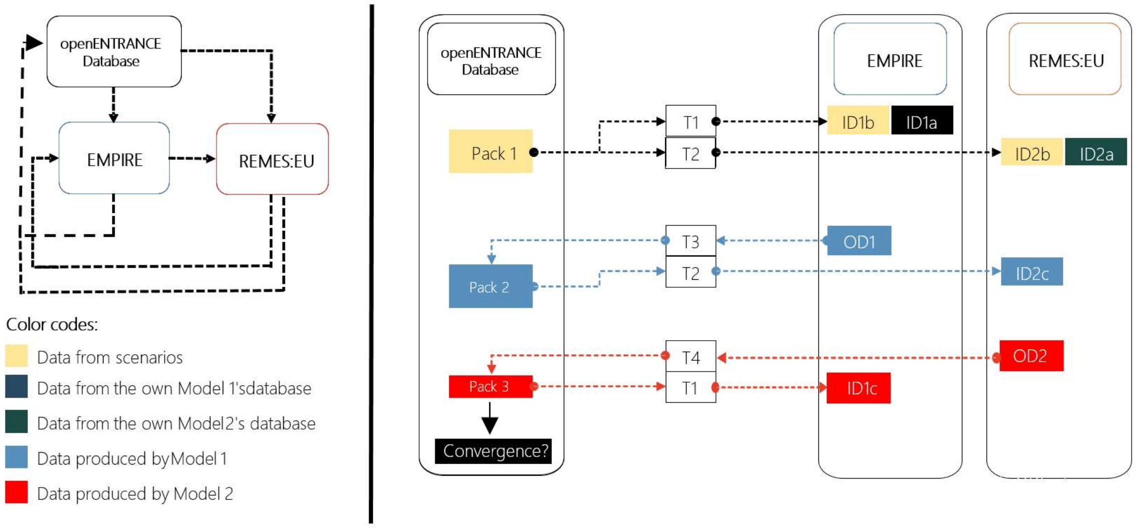


Figure 53 : Data workflow

The source and content of each dataPack is defined in the following table

dataPack	Data flow	Content, as example:
Pack 1	Input data from Scenarios, common between models	Fuels and CO2 prices in 2020 Technology operation costs Energy demand (baseline projection) Installed capacities
Pack 2	Output EMPIRE	Generation profiles Generation and transmission capacity Technology mix (percentage of each fuel used in energy production) Power technologies with their financial and technical parameters
Pack 3	Output REMES:EU	Total Energy demand CO2 prices GDP projections Value added Unemployment rate

The following table provides a definition of each considered dataPack

ID1a	Input dataset **"part a"** that comes from the **EMPIRE's own** database, *i.e. Energy system data*
ID1b	Input dataset **"part b"** that comes from the openENTRANCE database to **EMPIRE**, *i.e. energy demand, etc.*

ID2a	Input dataset **"part a"** that comes from the **REMES:EU**'s own s database, *i.e. Social Accounting Matrix, elasticities etc.*
ID2b	Input dataset **"part b"** that comes from the openENTRANCE database to **REMES:EU**, *i.e. Population Growth, Baseline GDP growth, etc.*
OD1	Output dataset from **EMPIRE** to the openENTRANCE database, *i.e. Technology mix*
ID2c	Input dataset **"part c"** from openENTRANCE database to **REMES:EU**, *i.e. Technology mix*
OD2	Output dataset from **REMES_EU** to the openENTRANCE database, *i.e. Energy demand*
ID1c	Input dataset **"part c"** that comes from the openENTRANCE database to **EMPIRE** , *i.e. Energy demand*

3.9.9 Data-exchange tools

To facilitate the exchange of information between the openENTRANCE database and the models IIASA has developed translation tools, i.e. code snippets that will convert the openENTRANCE common data format into information readable by the models and vice-versa. These tools (or translators) include:

- Unit conversions (e.g. EJ to MWh, MWh to GWh). (using the unit conversion available in OE platform)
- Geographical aggregation or disaggregation (using aggregation/disaggregation functions available in OE platform)
- Temporal aggregation or disaggregation (using aggregation/disaggregation functions available in OE platform)
- Formatting: i.e., converting the excel format to the adequate format. (columns, rows…)

As an example, in Figure 53 we have the following translators:

T1 (OE-EMPIRE)	Set of tools or methods to convert data from the **Common data format** to **EMPIRE** format
T2 (OE-REMES)	Set of tools or methods to convert data from the **Common data format** to **REMES:EU** format
T3 (EMPIRE-OE)	Set of tools or methods to convert data from the **EMPIRE** format to the **Common data format**
T4 (REMES-OE)	Set of tools or methods to convert data from the **REMES:EU** format to the **Common data format**

3.9.10 Execution order

This section provides the stepwise plan to carry out the case study, specifying the data exchanged (with the relevant data-exchange tools if appropriate). An example is provided below:

The detailed stepwise plan to carry out the case study is as follows

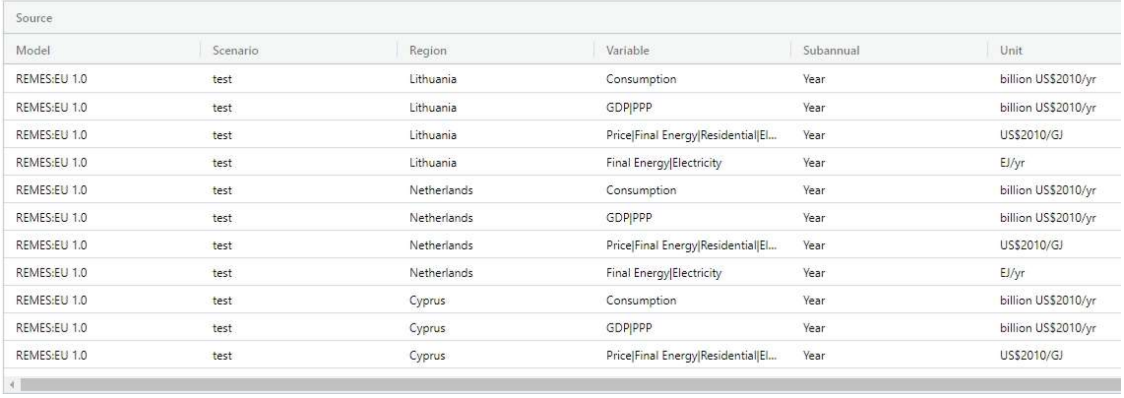
1. **Extraction of data from openENTRANCE Database:** First, the **Pack1** is built by selecting the adequate variables. **Pack1** is structured according to the common nomenclature. It is

transformed through **T1** and **T2** and **T3** and **T4** into **EMPIRE** and **REMES:EU**, data formats **ID1a** and **ID2a** respectively.

2. **Building EMPIRE Input dataset and running EMPIRE:** EMPIRE's dataset is built out of its own data (**ID1a**) and openENTRANCE Scenario data (**ID1b**). EMPIRE is executed and produces the output **OD1**. **OD1** is converted to the **Common data format** using **T3**, which produces **Pack2.**
3. **Exchanging between EMPIRE and REMES:EU**: Data from **Pack2** (produced by **EMPIRE**) are downloaded and converted to **REMES:EU** format using **T2**, obtaining **ID2c.**
4. **Building REMES:EU Input dataset and running REMES_EU:** The REMES:EU's dataset is built out of its own data (**ID2a**), openENTRANCE database (**ID2b**) and the information extracted from **Pack2** produced by EMPIRE (**ID2c**). REMES:EU is executed and produces the output **OD2**, which is converted to the **Common data format** using translator **T4**, which produces **Pack3**.
5. **Exchanging between REMES:EU and EMPIRE**: Data from **Pack3** (produced by **REMES:EU**) are downloaded and converted to **EMPIRE** format using **T1**, obtaining **ID1c**, which is an updated version of **ID1b**, containing information provided by **REMES:EU**, but downloaded from the **OpenENTRANCE** repository, just like in point 2. The process restarts from point 2.
6. The iterative procedure terminates when the euclidean norm of the difference between the vectors of variables provided to the platform in two subsequent iterations are smaller than a predefined threshold.

3.9.11 Implementation in the openENTRANCE scenario Explorer (screenshot)

In the following figure we show a screenshot containing a test dataset uploaded using the REMES:EU model as displayed in the openENTRANCE scenario explorer.



Source

Model	Scenario	Region	Variable	Subannual	Unit
REMES:EU 1.0	test	Lithuania	Consumption	Year	billion US$2010/yr
REMES:EU 1.0	test	Lithuania	GDP|PPP	Year	billion US$2010/yr
REMES:EU 1.0	test	Lithuania	Price|Final Energy|Residential|El...	Year	US$2010/GJ
REMES:EU 1.0	test	Lithuania	Final Energy|Electricity	Year	EJ/yr
REMES:EU 1.0	test	Netherlands	Consumption	Year	billion US$2010/yr
REMES:EU 1.0	test	Netherlands	GDP|PPP	Year	billion US$2010/yr
REMES:EU 1.0	test	Netherlands	Price|Final Energy|Residential|El...	Year	US$2010/GJ
REMES:EU 1.0	test	Netherlands	Final Energy|Electricity	Year	EJ/yr
REMES:EU 1.0	test	Cyprus	Consumption	Year	billion US$2010/yr
REMES:EU 1.0	test	Cyprus	GDP|PPP	Year	billion US$2010/yr
REMES:EU 1.0	test	Cyprus	Price|Final Energy|Residential|El...	Year	US$2010/GJ

Figure 54: Screenshot of a test dataset from the REMES:EU model

The uploaded data shows the evolution of the Gross Domestic Product, Electricity prices and demand and overall consumption expenditure for some of the analysed countries between 2010 and 2025. The model name needs to be equipped with the utilised version number, and followed by the name of the considered scenario, the name of the considered country, the variable, the temporal granularity – in this case left as yearly – and the measure unit used to quantify the output. After these descriptive entries the data is entered according to the explicit time granularity.

4. Concluding remarks and work ahead

openENTRANCE links a suit of energy modelling tools. The tools are of different character: energy system models (GENeSYS-MOD, SCOPE, HERO), models only for the electricity sector (EMPS/MAD plan4eu, TEPES, FRESH:COM, OSCARS), investment models (TEPES, EMPIRE, plan4eu) , pan-European and national models (GENeSYS-MOD, TEPES, EMPS/MAD, plan4eu, EMPIRE) versus local models (FRESH:COM, HERO and OSCARS) and also macro-economic models (REMES). By linking a suit models of different character, many aspects of the energy transition can be analysed in a consistent and efficient manner. So far, most studies based on linked energy system models include only two or a few models. For such studies, a tailormade format can be used to exchange data. When a whole suite of models is going to share data, like in openENTRANCE, a common and detailed data format used by all models is required. The openENTRANCE nomenclature includes a broad range of details for exchange of information among the models. Developing it has taken a significant amount of time. Both the nomenclature and the database developed in the project will be fully open and can be a first step for standardisation of the exchange of data between energy system models and for storing data for open energy models. The further use and development of these nomenclature and database in future energy modelling projects can significantly reduce the time spent on making modelling processes more efficient, models open, data accessible and modelling processes more transparent. Thus, the further use and development of the format and the nomenclature developed in the project is highly recommended. Since it is all fully open, the work can be brought further by any skilled research group.

This report describes the use of modelling tools and exchange of information among them, and with the Central Database, to take place in the context of the openENTRANCE project. This focuses on the analyses to take place within Case Studies, but also on the exchange of information between GENeSYS-MOD and the models to be used in these Case Studies. Thus, the model linkages to take place in the context of the project are carefully designed and described. The linkages here described are deemed to be general enough to cover those to take place in further pathway analyses within WP7.

Besides, the first stages of the implementation of these linkages, through the Central Database, have also been verified, carrying out the upload of a first set of data of each model onto the Database. The common, standard, openENTRANCE format for the exchange of data has been employed for this. This is based on the IAMC format, where all the relevant types of data managed by the models considered within the Case Studies have been included.

The efficiency, or optimality, of the linkages among models, within Case Studies, here described is to be ascertained for a specific case study (Case Study 3) within D5.1 in Task 5.1. Besides, the linkages reported here can be generally assessed through the consideration of best practices for model linkage derived in D5.1 (Task 5.1), as well as those compiled within this report.

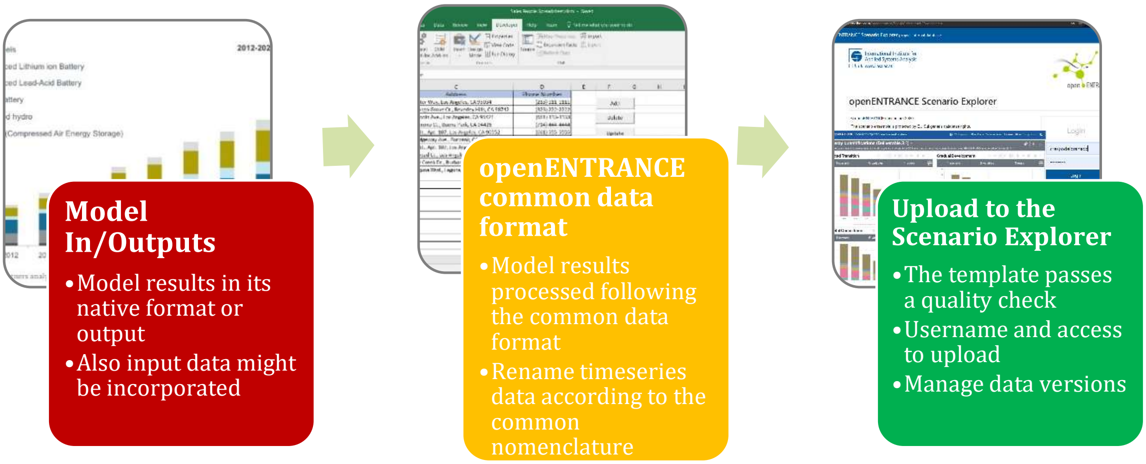
The process of model linkage implementation is still to be further pursued through the development of appropriate modules for data format conversion and download of the information stored in the Central Database that is required by models in Case Study analyses. Besides, the functioning of these modules is to be properly tested. This is to be accomplished within Case Study analyses in WP6.

'

Appendix A: Guideline to upload data to the openENTRANCE scenario explorer

This is a short guideline summarizing the main steps to upload and download data (model outputs or/and inputs) that conforms with the openENTRANCE data format and common nomenclature.

The openENTRANCE Scenario Explorer is a transparent modelling platform developed for disseminating and reusing modelling results. In order to assess, compare, and validate these results, a common nomenclature (i.e., common names of variables, regions, or units) is developed, based on the Integrated Assessment Modelling Consortium (IAMC) data format, which is already in use in several different integrated-assessment modelling comparisons. The IAMC data format is the standard used to upload the results of each model. The objective of the openENTRANCE Scenario Explorer and the underlying database is to facilitate exchange of input assumptions and outputs between models as well as to support transparency and openness of scenario results.



Model In/Outputs
- Model results in its native format or output
- Also input data might be incorporated

openENTRANCE common data format
- Model results processed following the common data format
- Rename timeseries data according to the common nomenclature

Upload to the Scenario Explorer
- The template passes a quality check
- Username and access to upload
- Manage data versions

As illustrated on the figure above, there are three main parts in the process of uploading timeseries data to the database accessible via the openENTRANCE Scenario Explorer. This is divided in the following main steps:

- **Step 1:** Access to the Scenario Explorer and prepare the output results of your model.
- **Step 2:** Convert the results to openENTRANCE template
- **Step 3**: Check the nomenclature
- **Step 4**: Send the file to IIASA (Daniel Huppmann) and specify the model name and version along with the usernames (people who can access it and modify), then upload
- **Step 5:** Create a workspace to visualize the uploaded data -> Screen shot of your model (snapshot to be included in D5.2 for each case study)

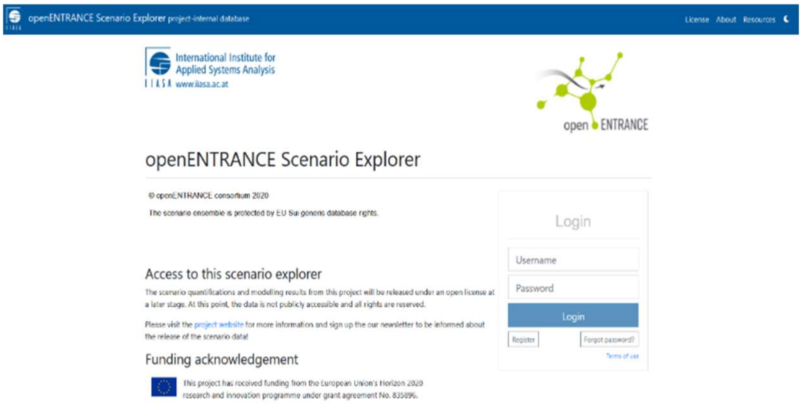
DETAIL PROCESS FOR EACH STEP:

Step 1
Access to the Scenario Explorer and prepare the output results of your model.

In this first step, the objective is to start getting familiar with the openENTRANCE Scenario Explorer. The openENTRANCE Scenario Explorer is available at https://data.ene.iiasa.ac.at/openENTRANCE

To get access to the platform, you have to follow the next steps:

- **Sign-on to the platform:** At the beginning, you have to create an account (click *Register* and fill in your details) or use an existent account for another IIASA scenario explorer (like the IAMC 1.5° Scenario Explorer showing the data underpinning the IPCC SR15)



openENTRANCE Scenario Explorer

© openENTRANCE consortium 2020

The scenario ensemble is protected by EU Sui generis database rights.

Access to this scenario explorer

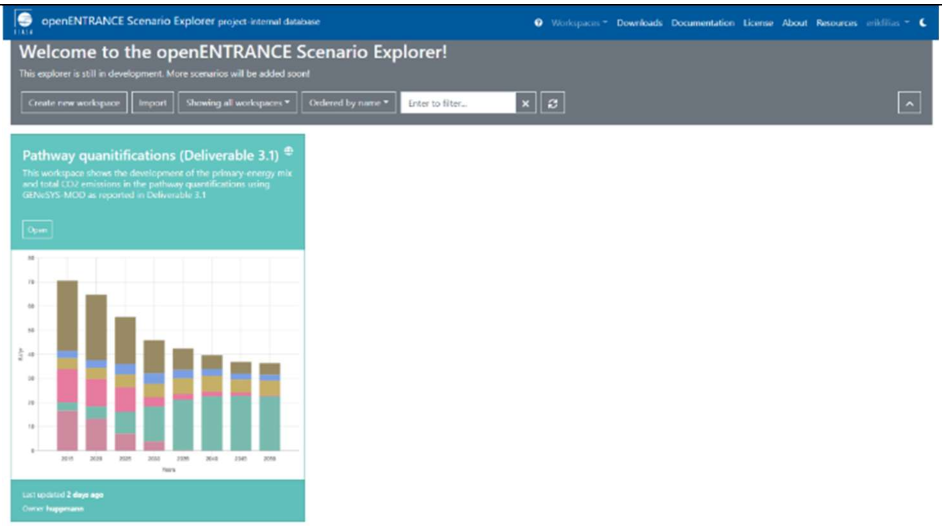
The scenario quantifications and modelling results from this project will be released under an open license at a later stage. At this point, the data is not publicly accessible and all rights are reserved.

Please visit the project website for more information and sign up the our newsletter to be informed about the release of the scenario data!

Funding acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 835896.

- **Get access rights:** Once you have activated your account, please send an email to IIASA with your username to get access permissions.
- **Log in and view scenario data:** After you have been granted access, you can log in and see pre-defined workspaces – or create your own workspace to explorer the scenario data.



Welcome to the openENTRANCE Scenario Explorer!

This explorer is still in development. More scenarios will be added soon!

Pathway quanitifications (Deliverable 3.1)

This workspace shows the development of the primary-energy mix and total CO2 emissions in the pathway quantifications using GENeSYS-MOD as reported in Deliverable 3.1

Last updated **2 days ago**

Owner **huppmann**

Now you have access to the Scenario Explorer. The initial page contains the workspaces. Start preparing your model input data and its underlying modelling features for the case or scenario you are about to run the analysis. The input and output data of your model, as explained in the next step, will have to be formatted to comply with the openENTRANCE common data format.

Step 2
Convert the results to the openENTRANCE template

Any data from your model that is shared via the open platform has to be converted to the openENTRANCE common data format, which is an extension of the IAMC data format. The data format is a tabular structure with the following columns.

model	scenario	region	variable	unit	subannual	2005	2010	2015
MESSAGE	CD-LINKS 400	World	Primary Energy	EJ/y	Year	462.5	500.7	...
...	...	...	...	...	...	...	...	...

For each column, the table entries have to follow the definitions from the nomenclature, which can be found on Github in the openENTRANCE repository:
github.com/openENTRANCE/nomenclature/

The table containing your data should be a .xlsx file. If there is data exchanged between models, which does not fit to any of the variables in the nomenclature, browse the discussion in https://github.com/openENTRANCE/nomenclature/issues to see if there is already an issue about a similar topic, or open a new issue. After agreeing on the implementation of new variables, units or regions, these items can be added to the nomenclature via pull-request.

Tips and FAQs:

Try to find the variables in the existing nomenclature and suggest a new variable only if really necessary to keep the nomenclature as neat and clean as possible. Do not leave blanks before and/or after the name of the variables. Note that the nomenclature is case-sensitive.

Step 3
Check the nomenclature

Check if all the *variables* and *regions* are indeed consistent with the openENTRANCE nomenclature by browsing the subfolders of the definitions in Github.

Optional step:

For those using Python, there is a Python module to automatically check if the nomenclature is followed. To install the module, there are two options:

1. **Recommended option:** Clone the Github repo and install from source in the working directory to which you cloned the repo (follow the steps explained here: https://github.com/openENTRANCE/nomenclature/tree/master/nomenclature#installation-instructions)

```
$ git clone git@github.com:openENTRANCE/nomenclature.git
$ cd nomenclature
$ pip install --editable .
```

2. Or directly from Github by typing the following in a command prompt:

```
pip install git+https://github.com/ openENTRANCE/nomenclature
```

To validate the model's output data according to the nomenclature, these two lines in Python (e.g. Jupyter script or in Spyder) are sufficient:

```
import nomenclature
nomenclature.validate(<file>)
```

where <file> is a .xlsx, .csv, or a pandas.DataFrame. nomenclature.validate should return True if the nomenclature is correct, False if the nomenclature is not followed. For each variable or region not defined in the nomenclature, there is a warning as:

```
WARNING:nomenclature:The following variables are not defined in the nomenclature: ['Emissions|CO2|Test']
```

Tips and FAQs:

- You have to use Python 3.7 to be able to use the nomenclature package properly.
- If you notice any smaller bugs and know how to fix them, you can propose a pull request on Github.
- If you have not worked with Python previously, you might want to download Anaconda (https://www.anaconda.com/products/individual) or miniconda (requires less disk space,

https://docs.conda.io/en/latest/miniconda.html). You can use Spyder or Jupyter for your Python scripts (included in Anaconda).

- If there are troubles installing the nomenclature module, you can discuss it on Github too. Maybe someone else encountered a similar problem before.

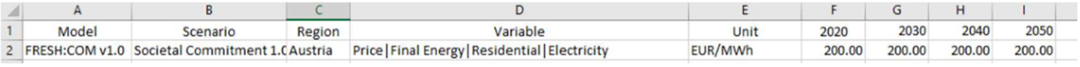
Step 4
Uploading to the IIASA Scenario Explorer

For the next step, it is necessary that the data table/file is consistent with the openENTRANCE nomenclature, otherwise the upload does not work!

- Prepare the remaining parts of the data file:
    - Add a version number to your model (e.g. Modelname v1.0) following semantic versioning
    - Scenario: Can be anything at the moment (e.g. Societal Commitment, Directed Transition, …)
- Send an email to IIASA, Daniel Huppmann (huppmann@iiasa.ac.at) with:
    - The data file (.xlsx)
    - Model name and version
    - Collaborators also working with the model (must also have access to the openENTRANCE Scenario Explorer)

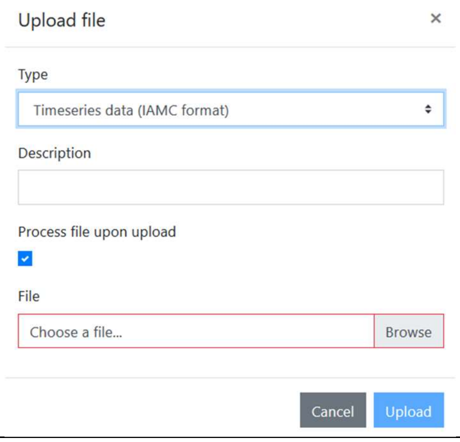
To get the permission to upload data to the Scenario Explorer.

Example



	A	B	C	D	E	F	G	H	I
1	Model	Scenario	Region	Variable	Unit	2020	2030	2040	2050
2	FRESH:COM v1.0	Societal Commitment 1.(	Austria	Price|Final Energy|Residential|Electricity	EUR/MWh	200.00	200.00	200.00	200.00

- Once you have the permission from Daniel, upload the data file (click on username in the top right corner, select Uploads, add new one, select IAMC format, choose a file and upload)



Upload file

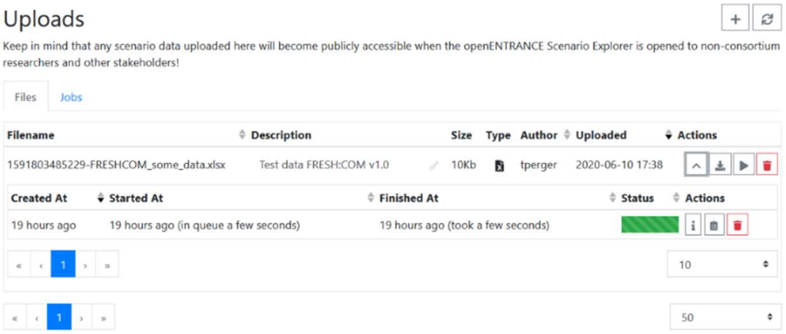
Type: Timeseries data (IAMC format)

Description

Process file upon upload ☑

File: Choose a file...

- After successfully uploading, you can see your file in *Uploads*:



Uploads

Keep in mind that any scenario data uploaded here will become publicly accessible when the openENTRANCE Scenario Explorer is opened to non-consortium researchers and other stakeholders!

Files Jobs

Filename	Description	Size	Type	Author	Uploaded	Actions
1591803485229-FRESHCOM_some_data.xlsx	Test data FRESH:COM v1.0	10Kb		tperger	2020-06-10 17:38	

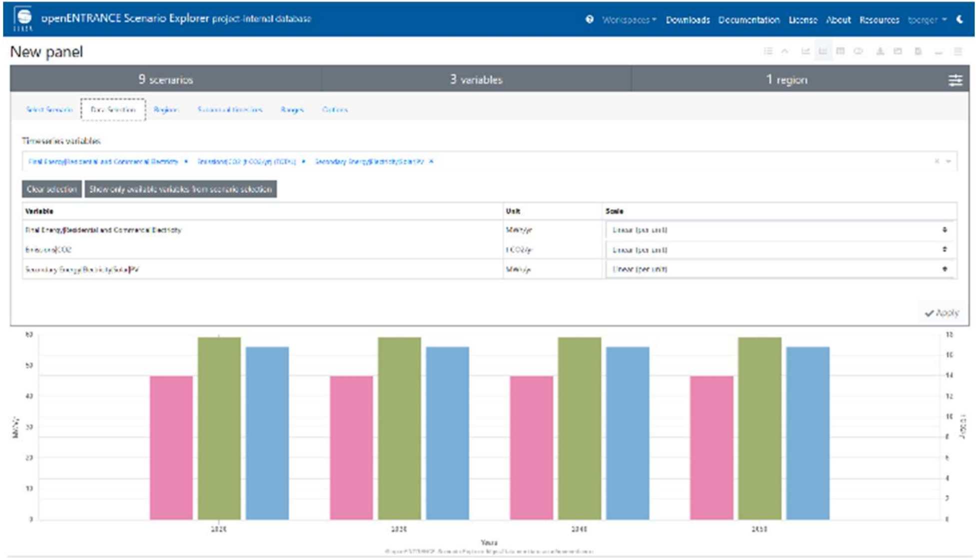
Created At	Started At	Finished At	Status	Actions
19 hours ago	19 hours ago (in queue a few seconds)	19 hours ago (took a few seconds)	🟩	

- Note that the upload will fail if there is an inconsistency with the nomenclature!
- Once the data is loaded, the user will receive an email containing the outcome of the upload.
- Any failed attempt can be analysed by clicking on the log link featured within the email
- Check the log file (Actions, show job log) for details if the upload failed.

Step 5
Create a workspace to visualize the upload

Go to https://data.ene.iiasa.ac.at/openENTRANCE/#/workspaces and create a new workspace. Select scenario, data, region, etc. (select the variables from your model that you want to visualize) and show as table, bar plot, or line graph.

Example from FRESH:COM:



Example from GENeSYS-MOD (four panels):

This workspace shows the development of the primary-energy mix and total CO2 emissions in the pathway quantifications using GENeSYS-MOD as reported in Deliverable 3.1

Tips and FAQs:

- You can play around with the workspace, show different scenarios, variables, etc.

The process to download data is rather straightforward. To download data one needs to open an available dataset from the Workspace page – in the above example we have seen the Pathway quantification, from the GENeSYS-MOD – using the button on the panel. At this point, one is presented with several graphs representing summarized information about the different scenarios. It is possible to download the data by clicking on the „download“ symbol on the top of each panel. It is also possible to create a new panel with a customized query by clicking on the + symbol on the top-right corner of the page and select the desired Scenario (Select Scenario), variables (Data Selection), regions (Regions), time granularity (Sub-annual time slices) and timespan (Ranges).

Appendix B: exhaustive variable list

The data exchange between the modelling teams and the openENTRANCE platform needs to be established using a clear and standardized protocol. As part of this protocol a common nomenclature is established to identify in the most comprehensive manner the list of variables that are exchanged in the modelling cases. An important focus of the project is to define a wide array of variables that are common between multiple research areas and that are expected to act as binders between those areas. In what follows, we report examples of lists of the openENTRANCE variables utilised in each case study. These variables are grouped into tables containing information on the source and the destination of each variable. All data that will be shared should be defined according to the Common data format described in GitHub - openENTRANCE/nomenclature. Namely, each table contains the number of the DataPack exchanged by the modelling team and the openENTRANCE platform, the name of the models involved in the exchange, the name of the variable taken from the openENTRANCE nomenclature with the related unit, the regions to be included, the time horizon and the time granularity. Part of the work for the completion of the nomenclature is ongoing during the drafting of this deliverable. Therefore, the notation reported in the tables will be partially subject to expansion.

Case study 1

Data Pack	Model (2 columns in case one data is input to one, output from another)	Variables (names from nomenclature)	Unit	Regions	Time horizon	Time granularity (related to each variable)
input data coming from openEntrance Scenarios	Plan4EU	Final Energy|Electricity	GWh	Countries available in openentrance scenarios	One year, usually 2050	Year
	Plan4EU	Final Energy|Electricity|Heat	GWh/yr			
	Plan4EU	Final Energy|Electricity|Transportation	EJ/yr GWh/yr			
	Plan4EU	Capacity|Electricity|<all generation technologies>	GW			
	Plan4EU	Capacity|Electricity|Electricity Storage	GW			
	Plan4EU	Capital Cost|Electricity|<	M€2015/GW			

		all generation technologies>				
	Plan4EU	CO2 Emissions|Electricity|<all generation technologies>	tons/MWh			
	Plan4EU	Variable Cost|Electricity||<all generation technologies>	€/MWh			
data coming from own plan4res database	Plan4EU	Final Energy|Electricity|Cooling	EJ/yr GWh/yr	Per country		
	Plan4EU	Final Energy|Electricity|Other	EJ/yr GWh/yr			
	Plan4EU	Capacity|Electricity|<all generation technologies>	GW	Per cluster: Balkans, Scandinavia, Baltics, Austria, Belgium, Switzerland, Czech Republic, Spain, Hungary, Ireland, The Netherlands, Poland, Portugal, Slovaquia, UK, Northern Italy, Southern Italy, France|SubGrid 23, France|SubGrid 24, France|SubGrid 25, ….., Germany|SubGrid 31,		
	Plan4EU	Maximum Active power|Electricity|<all thermal generation technologies>	MW	Per country		
	Plan4EU	Minimum Active power|Electricity|	MW			

		<all thermal generation technologies>				
	Plan4EU	Minimum On Duration|Electricity|<all thermal generation technologies>	hour			
	Plan4EU	Minimum Off Duration|Electricity|<all thermal generation technologies>	hour			
	Plan4EU	Forced Outage Rate|Electricity|Biomass|<all thermal generation technologies>	%			
	Plan4EU	Planned Outage Rate|Electricity|<all thermal generation technologies>	%			
	Plan4EU	Mean Outage Duration|Electricity|<all thermal generation technologies>	Day			
	Plan4EU	Rate Frequency Containment Reserve|Electricity|<all thermal generation technologies>	%			
	Plan4EU	Rate Automatic Frequency Restoration Reserve|Electricity|<all thermal generation technologies>	%			
	Plan4EU	Maximum Active power|Electricity|<solar, wind technologies>	MW			
	Plan4EU	Minimum Active power|Electricity|<solar, wind technologies>	MW			
	Plan4EU	Rate Frequency Containment Reserve|Electricity|<solar, wind technologies>	%			
	Plan4EU	Rate Automatic Frequency Restoration	%			

<table>
<tr><td></td><td></td><td>Reserve|Electricity|<solar, wind technologies></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Maximum Flow|Electricity|Transmission</td><td>MW</td><td>All interconnections between clusters</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Minimum Flow|Electricity|Transmission</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Final Energy|Electricity|Profile</td><td>MW</td><td>Per country</td><td></td><td>Hour</td></tr>
<tr><td></td><td>Plan4EU</td><td>Final Energy|Electricity|Cooling|Profile</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Final Energy|Electricity|Heat|Profile</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Final Energy|Electricity|Transportation|Profile</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Final Energy|Electricity|Other (excl. Heat, Cooling, Transport)|Profile</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Capacity|Electricity|Hydro|Reservoir</td><td>GW</td><td>Per cluster : France|SubGrid 14 … 27</td><td></td><td>year</td></tr>
<tr><td></td><td>Plan4EU</td><td>Capacity|Electricity|Hydro|Pumped Storage</td><td>GW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Capacity|Electricity|Hydro|Run-of-River</td><td>GW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Maximum Active power|Electricity|Hydro|reservoir</td><td>MW</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Maximum Storage|Electricity|Hydro|reservoir</td><td>MWh</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Pumping Efficiency|Electricity|Hydro|Reservoir</td><td>%</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Inflows|Electricity|Hydro|Reservoir</td><td>MWh</td><td></td><td></td><td>year</td></tr>
<tr><td></td><td>Plan4EU</td><td>Maximum Active power|Electricity|Hydro|Pumped Storage</td><td>MW</td><td></td><td></td><td>year</td></tr>
</table>

	Plan4EU	Minimum Active power|Electricity|Hydro|Pumped Storage	MW			
	Plan4EU	Maximum Storage|Electricity|Hydro|Pumped Storage	MWh			
	Plan4EU	Minimum Storage|Electricity|Hydro|Pumped Storage	MWh			
	Plan4EU	Pumping Efficiency|Electricity|Hydro|Pumped Storage	%			
	Plan4EU	Rate Frequency Containment Reserve|Electricity|Hydro|Pumped Storage	MW			
	Plan4EU	Minimum Active power|Electricity|Hydro|Pumped Storage	MW			
	Plan4EU	Maximum Active power|Electricity|Hydro|Run of River	MW			
	Plan4EU	Minimum Active power|Electricity|Hydro|Run of River	MW			
	Plan4EU	Rate Frequency Containment Reserve|Electricity|Hydro|Reservoir	%			
	Plan4EU	LoadFactor|Electricity|Hydro|Run of River|Profile	%			Hour
	Plan4EU	Inflows|Electricity|Hydro|Reservoir|Profile	%			
	Plan4EU	LoadFactor|Electricity|Solar|Profile	%			
	Plan4EU	LoadFactor|Electricity|Wind|OnShore|Profile	%			
	Plan4EU	LoadFactor|Electricity|Wind|OffShore|Profile	%			
	Plan4EU	Network|Electricity|Demand|Reserve|F	MWh	Per country		year

<table>
<tr><td></td><td></td><td>requency Containment</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td>Network|Electricity|Demand|Reserve|Automatic Frequency Restoration</td><td>MWh</td><td></td><td></td><td></td></tr>
<tr><td>Data output from Micro-econometric (ECHOES/PEAKapp) models</td><td>Micro-econometric</td><td>Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|<Technology></td><td>MW</td><td>NUTS 2</td><td>Annual</td><td>Representative hours in each month, e.g. 24 x 12 values.</td></tr>
<tr><td></td><td>Micro-econometric</td><td>Demand Response|Maximum Dispatch|Load Shifting|Electricity|Residential|<Technology></td><td>MW</td><td>NUTS 2</td><td>Annual</td><td>Representative hours in each month, e.g. 24 x 12 values.</td></tr>
</table>

EXAMPLE OF OUTPUT FROM MICRO-ECONOMETRIC (ECHOES/PEAKAPP) MODELS IN IAMC DATA FORMAT (AS CSV):

The below data give the load shifting potential from residential AC units at the NUTS 2 region level for 24 representative hours for each month. These data are defined in IAMC format to be compatible with the openENTRANCE platform.

```
Model,Scenario,Region,Variable,Unit,Subannual,2018

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h0,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h1,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h10,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h11,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h12,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h13,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h14,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h15,0.0
```

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h16,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h17,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h18,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h19,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h2,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h20,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h21,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h22,0.0

Flexibilities 2.1,baseline,AT11,Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|Air Conditioning,MW,M10h23,0.0

Case Study 2

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	FRESH:COM		Price|Final Energy|Residential|Electricity	EUR/kWh	EU27+NOR/CH	2050	year
	FRESH:COM		Price|Secondary Energy|Electricity	EUR/MWh			
	FRESH:COM		Emissions|CO2	Mt CO2/yr			
2	FRESH:COM		Final Energy|Residential and Commercial|Electricity	MWh/yr	EU27+NOR/CH	2050	year
	FRESH:COM		Investment|Energy Supply|Electricity|Solar	EUR/yr			
			Investment|Energy Supply|Electricity|Electricity Storage	EUR/yr			
	FRESH:COM		Emissions|CO2	Mt CO2/yr			

	FRESH:COM		Secondary Energy|Electricity|Solar|PV	MWh/yr			
	FRESH:COM		Capacity|Electricity|Solar|PV	GW			

Case Study 3

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	openENTRANCE		Final Energy|Electricity	MWh/yr	Balkans Scandinavia Baltics Austria Belgium Switzerland Czech Republic Spain Hungary Ireland Netherlands Poland Portugal Slovaquia UK Northern Italy Southern Italy Spain|ES111 Spain|ES112 Spain|ES130 ..... Norway|NO081 ...	2050	year
	openENTRANCE		Final Energy|Electricity|Transportation	MWh/yr			
	openENTRANCE		Final Energy|Electricity|Cooling	MWh/yr			
	openENTRANCE		Final Energy|Electricity|Heat	MWh/yr			
	openENTRANCE		Final Energy|Electricity|Other	MWh/yr			
	openENTRANCE		Capacity|Electricity	MWh/yr			
	openENTRANCE		Capacity|Electricity|Biomass	MW			
	openENTRANCE		Capacity|Electricity|Coal	MW			
	openENTRANCE		Capacity|Electricity|Gas	MW			
	openENTRANCE		Capacity|Electricity|Geothermal	MW			
	openENTRANCE		Final Energy|Electricity	MW		2050	hour
	openENTRANCE		Final Energy|Electricity|Transportation	MW			
	openENTRANCE		Final Energy|Electricity|Cooling	MW			
	openENTRANCE		Final Energy|Electricity|Heat	MW			
	openENTRANCE		Final Energy|Electricity|Other	MW			

4	openTEPES	openENTRANCE	Secondary Energy|Electricity|Hydro	MW		2050	hour
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Biomass	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Coal	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Gas	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Nuclear	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Solar	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Wind|Offshore	MW			
	openTEPES	openENTRANCE	Secondary Energy|Electricity|Wind|Onshore	MW			
3	openTEPES	EMPS&MAD	Power Flow|Electricity|Transmission	MW	ES111>ES112|cc1	2050	hour
	openTEPES	EMPS&MAD	Power Flow|Electricity|Transmission	MW	ES130>ES211|cc1		
	openTEPES	EMPS&MAD	Power Flow|Electricity|Transmission	MW	ES211>ES314|cc1		
	openTEPES	EMPS&MAD	Investment|Electricity|Transmission	MW	ES114>ES120|cc2		
	openTEPES	EMPS&MAD	Investment|Electricity|Transmission	MW	ES120>ES211|cc2		

Case Study 4

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	Plan4EU		Final Energy|Electricity	MWh/yr	Balkans Scandinavia Baltics Austria Belgium Switzerland Czech Republic	2050	year
	Plan4EU		Final Energy|Electricity|Transportation	MWh/yr			
	Plan4EU		Final Energy|Electricity|Cooling	MWh/yr			

	Plan4EU		Final Energy|Electricity|Heat	MWh/yr	Spain Hungary Ireland Netherlands Poland Portugal Slovaquia UK Northern Italy Southern Italy France|SubGrid 23 France|SubGrid 24 France|SubGrid 25 ..... Germany|SubGrid 31 ...		
	Plan4EU		Final Energy|Electricity|Other	MWh/yr			
	Plan4EU		Capacity|Electricity	MWh/yr			
	Plan4EU		Capacity|Electricity|Biomass	MW			
	Plan4EU		Capacity|Electricity|Coal	MW			
	Plan4EU		Capacity|Electricity|Gas	MW			
	Plan4EU		Capacity|Electricity|Geothermal	MW			
	Plan4EU		Final Energy|Electricity	MW		2050	hour
	Plan4EU		Final Energy|Electricity|Transportation	MW			
	Plan4EU		Final Energy|Electricity|Cooling	MW			
	Plan4EU		Final Energy|Electricity|Heat	MW			
	Plan4EU		Final Energy|Electricity|Other	MW			
	SCOPE SD		Emissions|CO2	Mt CO2/yr	AT BE BG CH CZ DE DK ES EE FI FR GB GR HR HU IE IT LT LU LV NL NO PL	2050	year
	SCOPE SD		Emissions|CO2|Energy	Mt CO2/yr			
	SCOPE SD		Emissions|CO2|Energy|Demand|Industry	Mt CO2/yr			
	SCOPE SD		Emissions|CO2|Energy|Demand|Residential and Commercial	Mt CO2/yr			
	SCOPE SD		Emissions|CO2|Energy|Demand|Transportation	Mt CO2/yr			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Biomass	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Coal	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Gas	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Hydrogen	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Hydropower	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Nuclear	GW			

	SCOPE SD	SCOPE SD	Capacity|Electricity|Oil	GW	PT RO SK SI SE		
	SCOPE SD	SCOPE SD	Capacity|Electricity|Solar	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Wind	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Wind|Offshore	GW			
	SCOPE SD	SCOPE SD	Capacity|Electricity|Wind|Onshore	GW			
	SCOPE SD	SCOPE SD	Capacity|Industrial Heat|<heating application>	GW			
	SCOPE SD	SCOPE SD	Capacity|Residential and Commercial Heat|<heating application>	GW			
	SCOPE SD	SCOPE SD	Capacity|Transport|Freight|<transport application>	GW			
	SCOPE SD	SCOPE SD	Capacity|Transformation|<transport application>	GW			
	SCOPE SD	SCOPE SD	Secondary Energy|Electricity|<generation application>	MWh/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Gases|< generation application >	MWh/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Hydrogen|…	MWh/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Industrial Heat|<heating application>	MWh/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Residential and Commercial Heat|<heating application>	MWh/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Transport|Freight|<transport application>	Gtkm/yr			
	SCOPE SD	SCOPE SD	Secondary Energy|Transport|Passenger|<transport application>	Gpkm/yr			
	SCOPE SD	SCOPE SD	Final Energy|Electricity	MWh/h		2050	hour
	SCOPE SD	SCOPE SD	Final Energy|Electricity|Transportation	MWh/h			

	SCOPE SD	SCOPE SD	`Final Energy|Electricity|Cooling`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Electricity|Heat`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Electricity|Other`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Industrial Heat|<heating application>`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Residential and Commercial Heat|<heating application>`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Transport|Freight|<transport application>`	MWh/h			
	SCOPE SD	SCOPE SD	`Final Energy|Transport|Passenger|<transport application>`	MWh/h			

Case Study 5

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time granularity (related to each variable)
Pack1	Plan4EU		`Final Energy|Electricity`	GWh	Countries available in openentrance scenarios	Year
	Plan4EU		`Final Energy|Electricity|Heat`	GWh/yr		
	Plan4EU		`Final Energy|Electricity|Transportation`	EJ/yr GWh/yr		
	Plan4EU		`Capacity|Electricity|<all generation technologies>`	GW		
	Plan4EU		`Capacity|Electricity|Electricity Storage`	GW		
	Plan4EU		`Capital Cost|Electricity|<all generation technologies>`	M€2015 /GW		
	Plan4EU		`Emissions|CO2|Electricity||Electricity|<all generation technologies>`	tons/MWh		
	Plan4EU		`Variable Cost|Electricity||<all generation technologies>`	€/MWh		
	Plan4EU		`Demand Response|Maximum Reduction|Load Shifting|Electricity|Residential|<all household technologies>`	MW		Hour (of a typical day for each month of the year)

	Plan4EU		Demand Response|Maximum Dispatch|Load Shifting|Electricity|Residential|<all household technologies>	MW		Hour (of a typical day for each month of the year)
Pack2	Plan4EU		Final Energy|Electricity|Cooling	EJ/yr GWh/yr	Per country	year
	Plan4EU		Final Energy|Electricity|Other	EJ/yr GWh/yr		
	Plan4EU		Inertia|Electricity|<all technologies providing inertia>	s	europe	
	Plan4EU		Capacity|Electricity|<all generation technologies>	GW	Per cluster[i];	
	Plan4EU		Capacity|Electricity|Electricity Storage	GW	Per cluster	
	Plan4EU		Capacity|Electricity|Transmission	GW	Per Transmission line	
	Plan4EU		Capacity|Electricity| Distribution	GW	Per Distribution line	
	Plan4EU		Capital Cost|Electricity|Transmission	€/MW	Per Transmission line	
	Plan4EU		Capital Cost|Electricity|Distribution	€/MW	Per Distribution line	
	Plan4EU		Maximum Active power|Electricity|<all thermal generation technologies>	MW	Per country	
	Plan4EU		Minimum Active power|Electricity|<all thermal generation technologies>	MW		
	Plan4EU		Minimum On Duration|Electricity|<all thermal generation technologies>	hour		
	Plan4EU		Minimum Off Duration|Electricity|<all thermal generation technologies>	hour		
	Plan4EU		Forced Outage Rate|Electricity|Biomass|<all thermal generation technologies>	%		
	Plan4EU		Planned Outage Rate|Electricity|<all thermal generation technologies>	%		
	Plan4EU		Mean Outage Duration|Electricity|<all thermal generation technologies>	Day		
	Plan4EU		Rate Frequency Containment Reserve|Electricity|<all thermal generation technologies>	%		
	Plan4EU		Rate Automatic Frequency Restoration Reserve|Electricity|<all thermal generation technologies>	%		

	Plan4EU		Maximum Active power|Electricity|<solar, wind technologies>	MW		
	Plan4EU		Minimum Active power|Electricity|<solar, wind technologies>	MW		
	Plan4EU		Rate Frequency Containment Reserve|Electricity|<solar, wind technologies>	%		
	Plan4EU		Rate Automatic Frequency Restoration Reserve|Electricity|<solar, wind technologies>	%		
	Plan4EU		Maximum Flow|Electricity|Transmission	MW	All interconnections between clusters	
	Plan4EU		Minimum Flow|Electricity|Transmission	MW		
	Plan4EU		Final Energy|Electricity|Profile	MW	Per country	Hour
	Plan4EU		Final Energy|Electricity|Cooling|Profile	MW		
	Plan4EU		Final Energy|Electricity|Heat|Profile	MW		
	Plan4EU		Final Energy|Electricity|Transportation|Profile	MW		
	Plan4EU		Final Energy|Electricity|Other (excl. Heat, Cooling, Transport)|Profile	MW		
	Plan4EU		Capacity|Electricity|Hydro|Reservoir	GW	Per cluster : France|Sub Grid 14 ... 27	year
	Plan4EU		Capacity|Electricity|Hydro|Pumped Storage	GW		
	Plan4EU		Capacity|Electricity|Hydro|Run-of-River	GW		
	Plan4EU		Maximum Active power|Electricity|Hydro|reservoir	MW		
	Plan4EU		Maximum Storage|Electricity|Hydro|reservoir	MWh		
	Plan4EU		Pumping Efficiency|Electricity|Hydro|Reservoir	%		
	Plan4EU		Inflows|Electricity|Hydro|Reservoir	MWh		year
	Plan4EU		Maximum Active power|Electricity|Hydro|Pumped Storage	MW		year
	Plan4EU		Minimum Active power|Electricity|Hydro|Pumped Storage	MW		
	Plan4EU		Maximum Storage|Electricity|Hydro|Pumped Storage	MWh		
	Plan4EU		Minimum Storage|Electricity|Hydro|Pumped Storage	MWh		

	Plan4EU		`Pumping Efficiency|Electricity|Hydro|Pumped Storage`	%		
	Plan4EU		`Rate Frequency Containment Reserve|Electricity|Hydro|Pumped Storage`	MW		
	Plan4EU		`Minimum Active power|Electricity|Hydro|Pumped Storage`	MW		
	Plan4EU		`Maximum Active power|Electricity|Hydro|Run of River`	MW		
	Plan4EU		`Minimum Active power|Electricity|Hydro|Run of River`	MW		
	Plan4EU		`Rate Frequency Containment Reserve|Electricity|Hydro|Reservoir`	%		
	Plan4EU		`LoadFactor|Electricity|Hydro|Run of River|Profile`	%		Hour
	Plan4EU		`Inflows|Electricity|Hydro|Reservoir|Profile`	%		
	Plan4EU		`LoadFactor|Electricity|Solar|Profile`	%		
	Plan4EU		`LoadFactor|Electricity|Wind|OnShore|Profile`	%		
	Plan4EU		`LoadFactor|Electricity|Wind|OffShore|Profile`	%		
	Plan4EU		`Network|Electricity|Demand|Reserve|Frequency Containment`	MWh	Per country	year
	Plan4EU		`Network|Electricity|Demand|Reserve|Automatic Frequency Restoration`	MWh		
Pack3	Plan4EU		`Investment|Energy Supply|Electricity|<all generation technologies>`	billion US$2010/yr	Per cluster	Year
	Plan4EU		`Investment|Energy Supply|Electricity|Energy Storage Systems`	billion US$2010/yr		
	Plan4EU		`Investment|Energy Supply|Electricity|Transmission`	billion US$2010/yr		
	Plan4EU		`Investment|Energy Supply|Electricity|Distribution`	billion US$2010/yr		
	Plan4EU		`Capacity|Electricity|<all generation technologies>`	GW		
	Plan4EU		`Capacity|Electricity|Electricity Storage`	GW		
	Plan4EU		`Capacity|Electricity|Transmission`	GW	Per Transmission line	Year
	Plan4EU		`Capacity|Electricity|Distribution`	GW	Per Distribution line	
	Plan4EU		`Emissions|CO2|Energy|Supply|Electricity`	Mt CO2/yr	Per cluster	Year

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<tr><th></th><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Active Power|Electricity|<all thermal technologies></td><td>MWh</td><td>Per cluster</td><td>hour</td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Active Power|Electricity|<all storage technologies></td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Active Power|Electricity|<all demand response technologies></td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Storage|Electricity|Hydro|<all hydro technologies></td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Storage|Electricity|Energy Storage System</td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Storage|Electricity|Load Curtailement</td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Operation Cost|Electricity|<all technologies></td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Reserve|Electricity|Automatic Frequency Restoration|<all technologies></td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Reserve|Electricity|Frequency Containment||<all technologies></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Inertia|Electricity|<all technologies></td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|CO2 Emissions|Electricity</td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Final Energy|Electricity</td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Maximum Flow|Electricity|Transmission</td><td>billion US$2010/yr</td><td>Per transmission line</td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Minimum Flow|Electricity|Transmission</td><td>billion US$2010/yr</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Network|Electricity|Demand|Inertia</td><td>MWh</td><td>Per cluster</td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Network|Electricity|Demand|Reserve|Automatic Frequency Restoration</td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Marginal Cost|Network|Electricity|Demand|Reserve|Frequency Containment</td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Demand-not-served|Electricity</td><td>MWh</td><td></td><td></td></tr>
<tr><td></td><td>Plan4EU</td><td></td><td>Value of Lost Load|Electricity</td><td></td><td></td><td>year</td></tr>
</table>

Case Study 6

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	eTransport		Final Energy|Electricity	MWh/h	Furuset Oslo Norway	2050	Preferably we would use a time granularity of hourly resolution, in cases where there is only hourly resolution available, if necessary, the data will be dissggregated to sufficient resolution
	eTransport		Final Energy|Hot water	MWh/h			
	eTransport		Final Energy|Electricity|Cooling	MWh/h			
	eTransport		Final Energy|Electricity|Heat	MWh/h			
	eTransport		Final Energy|Heating	MWh/h			
	eTransport		Final Energy|Hydrogen	MWh/h			
	eTransport		Capacity|Electricity	MW			
	eTransport		Capacity|Electricity|Hydro	MW			
	eTransport		Capacity|Electricity|PV solar	MW			
2	eTransport		Capacity|Electricity storage	MW			
	eTransport		Capacity|Heat Storage	MW			
	eTransport		Capacity|Hydrogen storage	MW			
	eTransport		Price|Waste	Euro/MWh			
	eTransport		Price|Biomass	Euro/MWh			
	eTransport		Price|Natural gas	Euro/MWh			

Case Study 7

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	Plan4EU		Primary Energy|Biomass	MWh/h	Denmark	2050	hourly
	Plan4EU		Capacity|Electricity	MWh/h			
	Plan4EU		Price|Carbon	EUR/t			
	Plan4EU		Price|Biomass	EUR/MWh			
	Plan4EU		Final Energy|Electricity	MWh/h			
	Plan4EU		CO2 Emissions|Electricity|<all generation technologies>	tons/MWh			
2	Plan4EU		Final Energy|Electricity|Heat	MWh/h		2050	hourly
	Frigg		Final Energy|Electricity|Heat	MWh/h			

	Frigg	Plan4EU	`Price|MarginalCost`	EUR/(MWh/h)			

Case Study 8

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	OsemoSYS		Final Energy|Electricity	MWh/yr	Balkans Scandinavia Baltics Austria Belgium Switzerland Czech Republic Spain Hungary Ireland Netherlands Poland Portugal Slovaquia UK Northern Italy Southern Italy France|SubGrid 23 France|SubGrid 24 France|SubGrid 25 ..... Germany|SubGrid 31 ...	2050	year
	OsemoSYSU		Final Energy|Electricity|Transportation	MWh/yr			
	OsemoSYS		Final Energy|Electricity|Cooling	MWh/yr			
	OsemoSYS		Final Energy|Electricity|Heat	MWh/yr			
	OsemoSYS		Final Energy|Electricity|Other	MWh/yr			
	OsemoSYS		Capacity|Electricity	MWh/yr			
	OsemoSYS		Capacity|Electricity|Biomass	MW			
	OsemoSYS		Capacity|Electricity|Coal	MW			
	OsemoSYS		Capacity|Electricity|Gas	MW			
	OsemoSYS		Capacity|Electricity|Geothermal	MW			
	OsemoSYS		Final Energy|Electricity	MW		2050	hour
	OsemoSYS		Final Energy|Electricity|Transportation	MW			
	OsemoSYS		Final Energy|Electricity|Cooling	MW			
	OsemoSYS		Final Energy|Electricity|Heat	MW			
	OsemoSYS		Final Energy|Electricity|Other	MW			

Case Study 9

Data Pack	Model (2 columns in case one data is input to one, output from another)		Variables (names from nomenclature)	Unit	regions	Time horizon	Time granularity (related to each variable)
1	REMES:EU		population	million	Lithuania Latvia Estonia Sweden Denmark Austria Belgium Switzerland Czech Republic Spain Hungary Ireland Netherlands Poland Portugal Slovakia UK Italy France Germany Cyprus Norway	2050	Every 5 years
1	REMES:EU		Price|Final Energy|Residential|Electricity	EJ/yr			
1	REMES:EU		Final Energy|Electricity	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Biomass	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Coal	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Fossil	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Gas	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Hydrogen	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Hydro	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Nuclear	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Ocean	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Oil	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Solar	EJ/yr			
2	REMES:EU		Secondary Energy|Electricity|Wind	EJ/yr			
3	REMES:EU		Final Energy|Electricity	EJ/yr			
3	REMES		Price|Final Energy|Residential|Electricit	US$2010/GJ			
3	REMES:EU		GDP|PPP	Bil. US$2010/yr			