Introduction to CLEWs

Hands-on lecture 3: Creating a simple energy model with OSeMOSYS

V2.0

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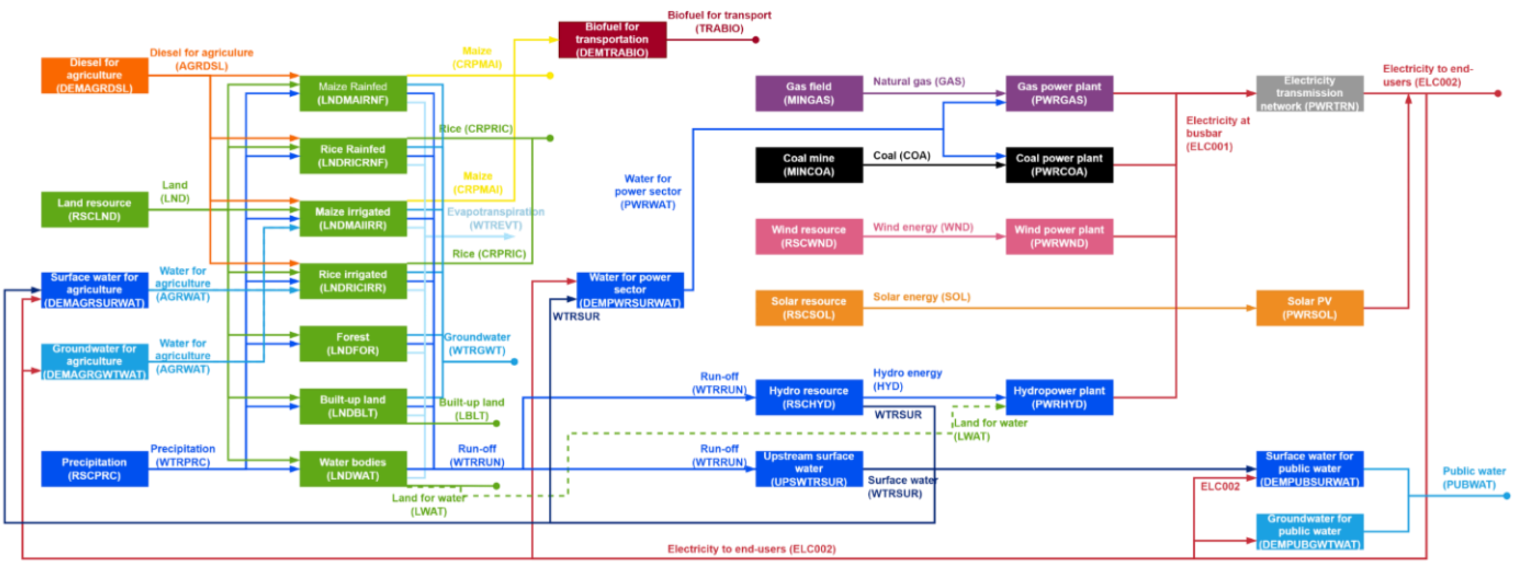
Tags: CLEWs; Climate; Land; Energy; Water; Systems Modelling; Integrated; Policy Coherence; Installation; Hands-on; Climate Compatible Growth; Open Source; Teaching Kit.

Useful links:

1) Energy Modelling Community (EMC) Discourse Forum – please use this for any CLEWs-related discussions, especially troubleshooting queries!
2) EMC LinkedIn.
3) CCG YouTube.
4) Hands-on Solutions can be found here.

Overview

The figure below gives an overview of the CLEWs model you will create by the end of all the hands-on sessions. You will build it little by little, starting with this hands-on session. The figure shows a Reference CLEWs Diagram (RCD). As discussed in the lecture material, the boxes represent technologies, processes, or physical assets. The lines represent flows of commodities.



The names of the technologies and commodities follow a specific naming convention that you will have to maintain throughout the exercise; otherwise, you will not be able to visualize the results of your exercises!

The summary of the naming convention is given in the table below. You do not have to memorise it; you will be gradually introduced to it with every hands-on session. However, you can always come back to this table if you are uncertain. It includes all technologies and commodities that you will encounter through all hands-on sessions.

Name	Description
Technologies	
RSCLND	Land resource
LNDMAIRNF	Land representing rainfed maize cultivation

LNDRICRNF	Land representing rainfed rice cultivation
LNDMAIIRR	Land representing irrigated maize cultivation
LNDRICIRR	Land representing irrigated rice cultivation
LNDFOR	Land representing forests
LNDBLT	Land representing built-up land
LNDWAT	Land representing water bodies
RSCPRC	Precipitation water resource
MINGAS	Gas extraction
MINCOA	Coal extraction
RSCHYD	Hydro resource for power
RSCSOL	Solar resource for power
RSCWND	Wind resource for power
PWRGAS	Gas power plant
PWRCOA	Coal power plant
PWRHYD	Hydro power plant
PWRSOL	Rooftop solar photovoltaic
PWRWND	Wind turbines
PWRTRN	Transmission and distribution network
DEMAGRDSL	Diesel used in the agriculture sector
DEMAGRSURWAT	Surface water supply for agriculture
DEMAGRGWTWAT	Ground water supply for agriculture
DEMPWRSURWAT	Surface water supply for power plants
DEMPWRGWTWAT	Ground water supply for power plants
DEMPUBSURWAT	Surface water supply for public use
DEMPUBGWTWAT	Ground water supply for public use
DEMTRABIO	Biofuel for transport
Commodities	
LND	Land
CRPMAI	Maize
CRPRIC	Rice
WTRPRC	Precipitation water
AGRWAT	Agricultural water

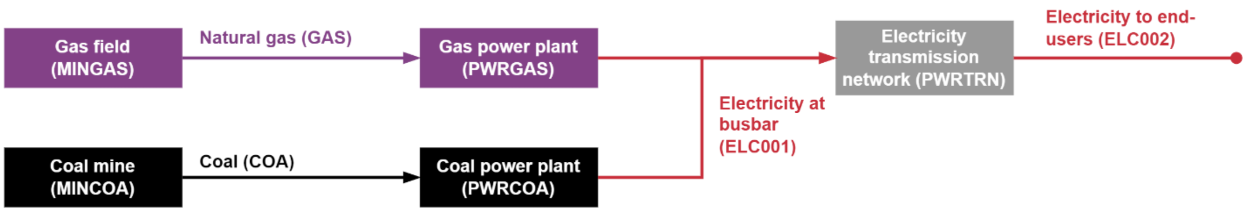
WTREVT	Evapotranspired water
WTRGWT	Ground water
WTRSUR	Surface water
PWRWAT	Water for power plants
PUBWAT	Public water
GAS	Natural gas
COA	Coal
HYD	Hydro
SOL	Solar
WND	Wind
ELC001	Electricity fed to transmission and distribution network
ELC002	Electricity for final uses
AGRDSL	Diesel used in the agriculture sector
LFOR	Land representing forests
LBLT	Land representing built-up land
LWAT	Land representing water bodies
TRABIO	Biofuel for transport

Learning outcomes

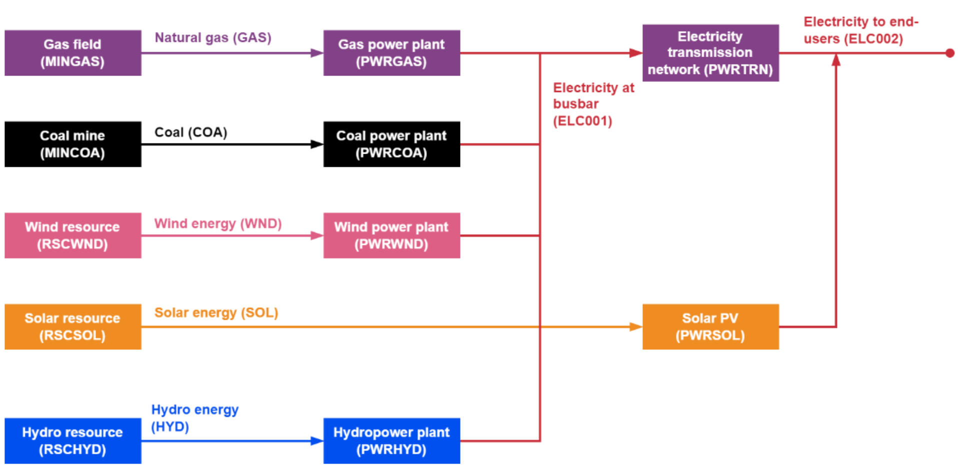
By the end of hands-on exercise, you will be able to:

1) Create a simple energy supply-demand chain
2) Understand and use key numerical data for the technologies and commodities
3) Run a simple model and analyse the results

Throughout this exercise, you will create a new simple energy system model and reflect on how it works and how its results change with input changes. Building a simple energy system model representing the extraction of coal and natural gas for the transformation into electricity in power plants to meet an annual demand.



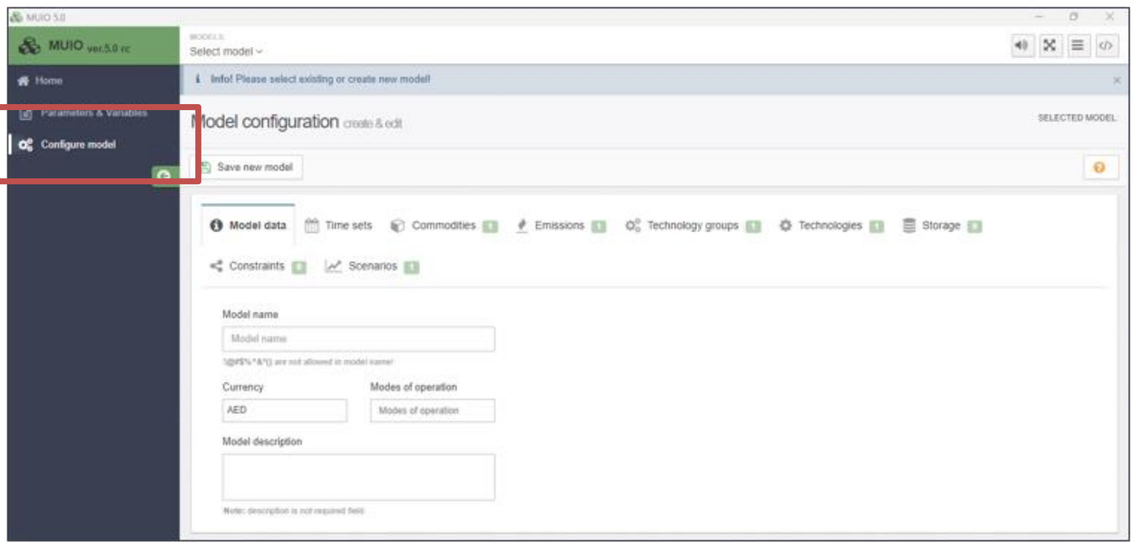
The figure below gives an overview of the energy system model you will create by the end of this Hands-on Exercise. You will build it little by little, starting with this exercise. The figure shows a 'Reference Energy System' (RES). As discussed during the lectures, the boxes represent technologies, processes, or physical assets. The lines represent flows of commodities.



Activity 1 – Introduce new technologies and commodities

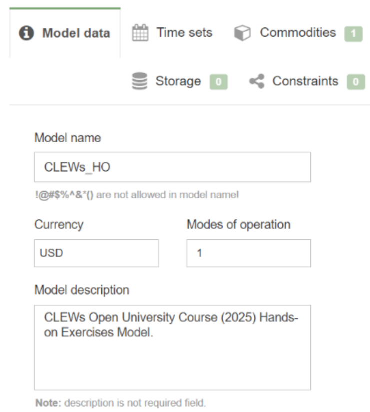
The starting point for this activity will be to create a new model in the MUIO. You will have to configure a new model and add some inputs.

1. On the left-hand side menu, select “Configure model”.



2. Fill in the fields in the “Model data” tab with the following information:
    - Model name: CLEWs_HO3 -> then when you work on future versions, you will download and save your current version. Then create a copy of that version and rename it (e.g. CLEWs_HO4 and so on).
    - Description: CLEWs Open University Course (2025) Hands-on Exercises Model.

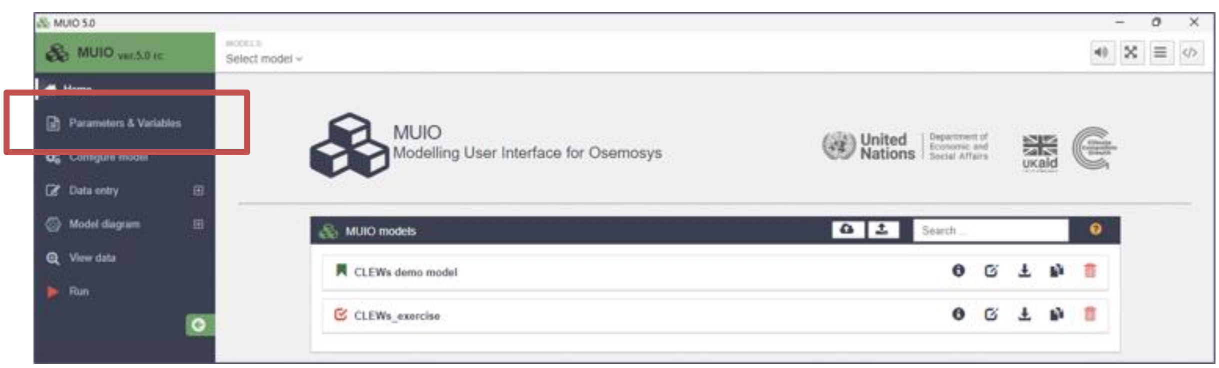
- Currency: USD
- Modes of Operation: 1



3. Click on “Save new model” to save your edits and create the model.

   The tool you are using (OSeMOSYS) is a cost-minimization tool. That is, it decides investments and operation of technologies based on their costs. If technologies have no costs at all, the resulting capacities and activities of technologies may show unreasonably high and non-meaningful numbers. Until we get to properly defining costs, let us make sure that there is some non-zero 'default' value in the model, to avoid strange results.

4. Select your model in the **Home** screen and click on 'Parameters and Variables' on the left side.

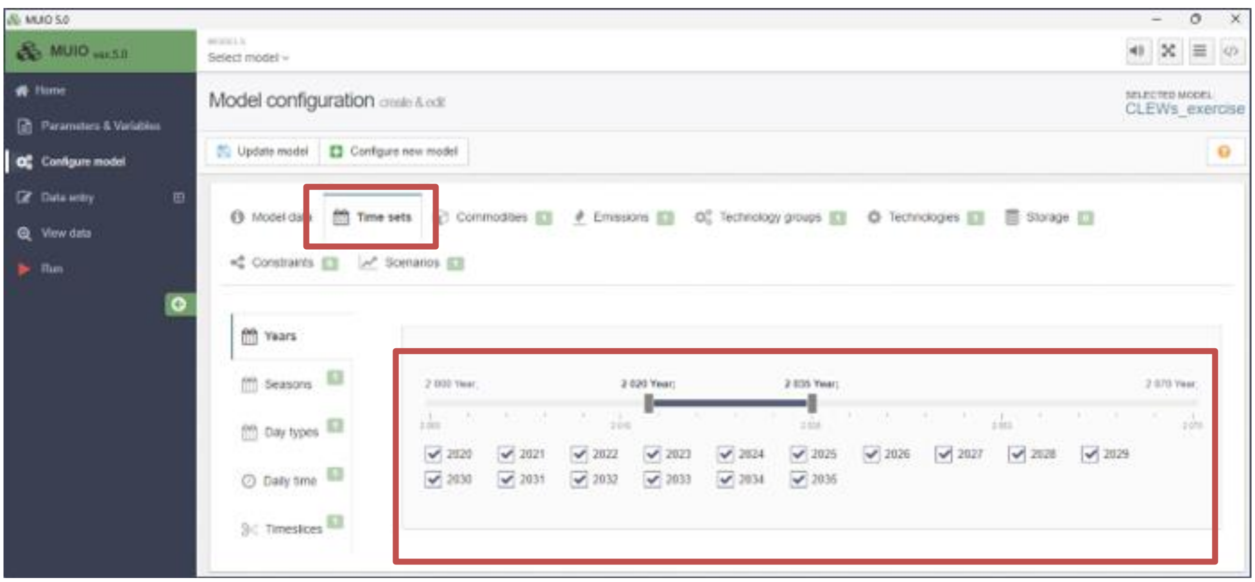


5. In the window that opens, look for the lines of 'Capital costs', 'Fixed costs' and 'Variable costs', make sure that each has a Default value of 0.0001 (or overwrite the 0 if not), and save.

Region, year, technology	Capital Cost	0.00010	10^[Currency]/[Technol...	Update rule
Region, year, technology	Fixed Cost	0.00010	10^[Currency]/[Technol...	Update rule
Region, year, technology	Residual Capacity	0.00000	[Technology capacity unit]	Update rule
Region, year, technology	Total Annual Max Capacity	999,999.00000	[Technology capacity unit]	Update rule
Region, year, technology	Total Annual Max Capacity Investment	999,999.00000	[Technology capacity unit]	Update rule
Region, year, technology	Total Annual Min Capacity	0.00000	[Technology capacity unit]	Update rule
Region, year, technology	Total Annual Min Capacity Investment	0.00000	[Technology capacity unit]	Update rule
Region, year, technology	Total Technology Annual Activity Lower Limit	0.00000	[Technology activity unit]	Update rule
Region, year, technology	Total Technology Annual Activity Upper Limit	999,999.00000	[Technology activity unit]	Update rule
Region, year, technology	Capacity Of One Technology Unit	0.00000	[Technology capacity unit]	Update rule
Region, year, technology, mode...	Variable Cost	0.00010	10^[Currency]/[Technol...	Update rule

6. Go to the tab "Time sets" in "Model configuration".

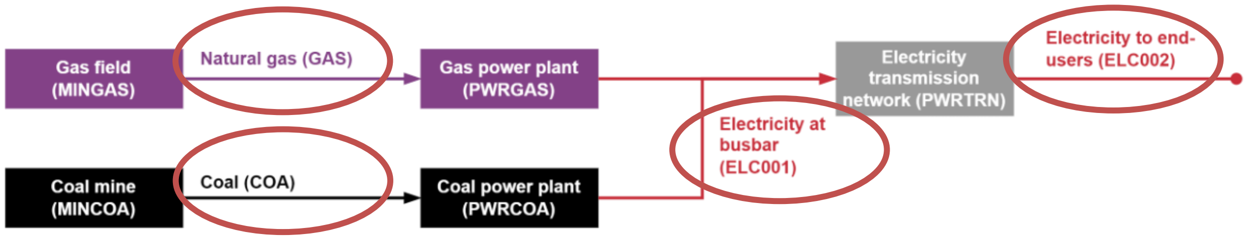
   In the section "**Years**", adjust the levers to set the model period to 2020 –2035 (or unselect the years not in the model period).



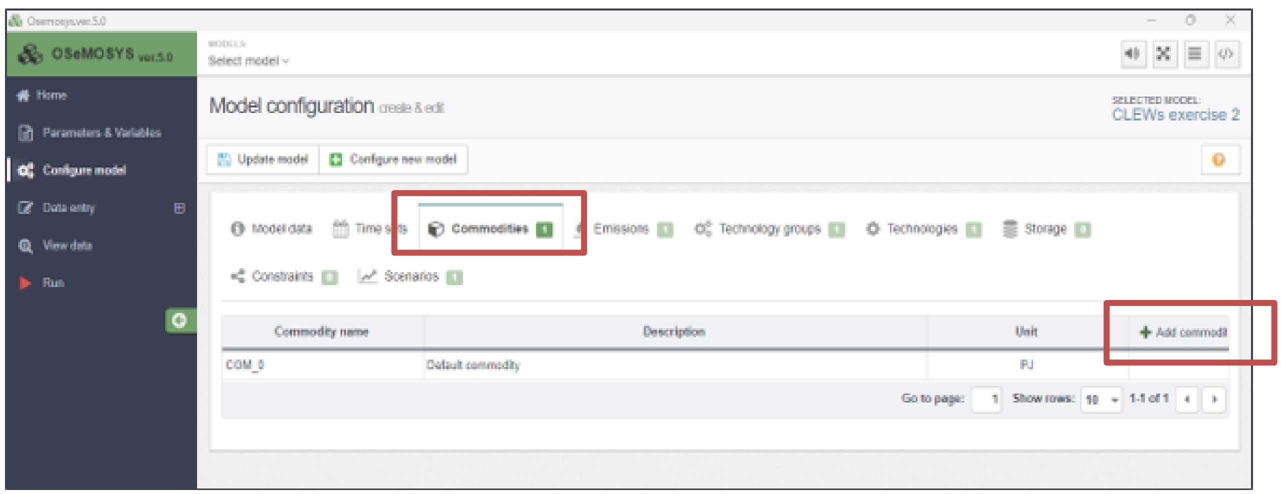
7. Click on "**Update model**" *(top left of config page)* to save your edits.

^ Always do this, at the end of any step, with any element you modify!

8. In the section “Configure Model”, select the tab “Commodities” to add commodities (lines in the RES).



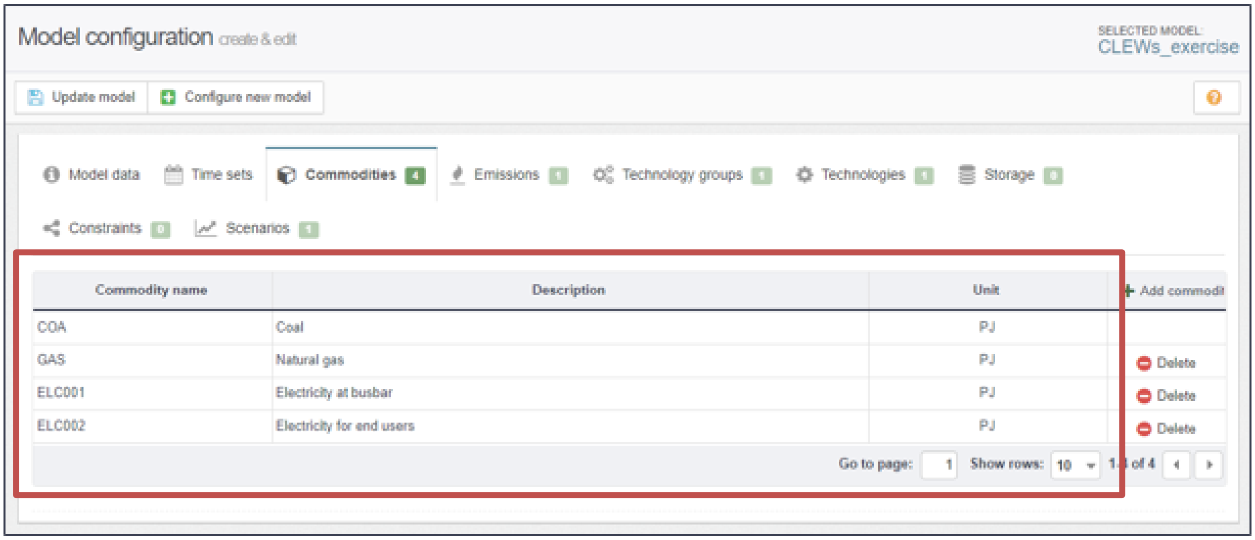
9. Create 4 commodities by editing the name of the default commodity and adding 3 others using the “+ Add commodity” button to the right.



10. **Consider the following names and descriptions**. Keep the unit as “PJ”.

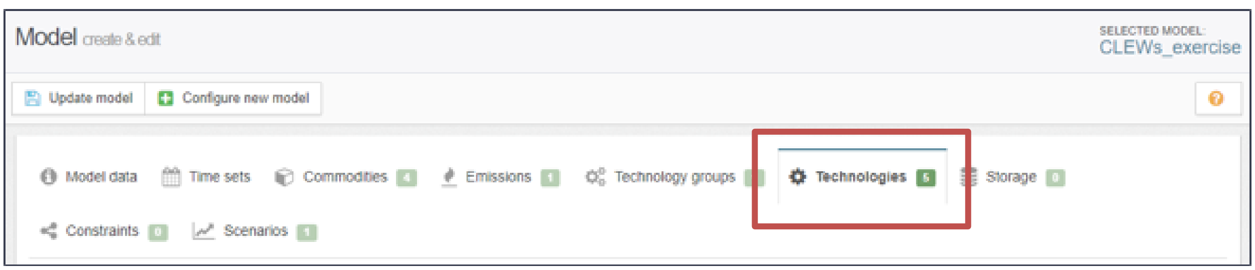
No	**Commodity**	**Description**	**Unit**
1	**COA**	**Coal**	**PJ**
2	**GAS**	**Natural Gas**	**PJ**
3	**ELC001**	**Electricity at Busbar**	**PJ**
4	**ELC002**	**Electricity for end users**	**PJ**

(exactly as indicated above, with no spaces, nor special characters – any deviation from the names indicated above may make the model crash and/or prevent you from visualizing results later on)

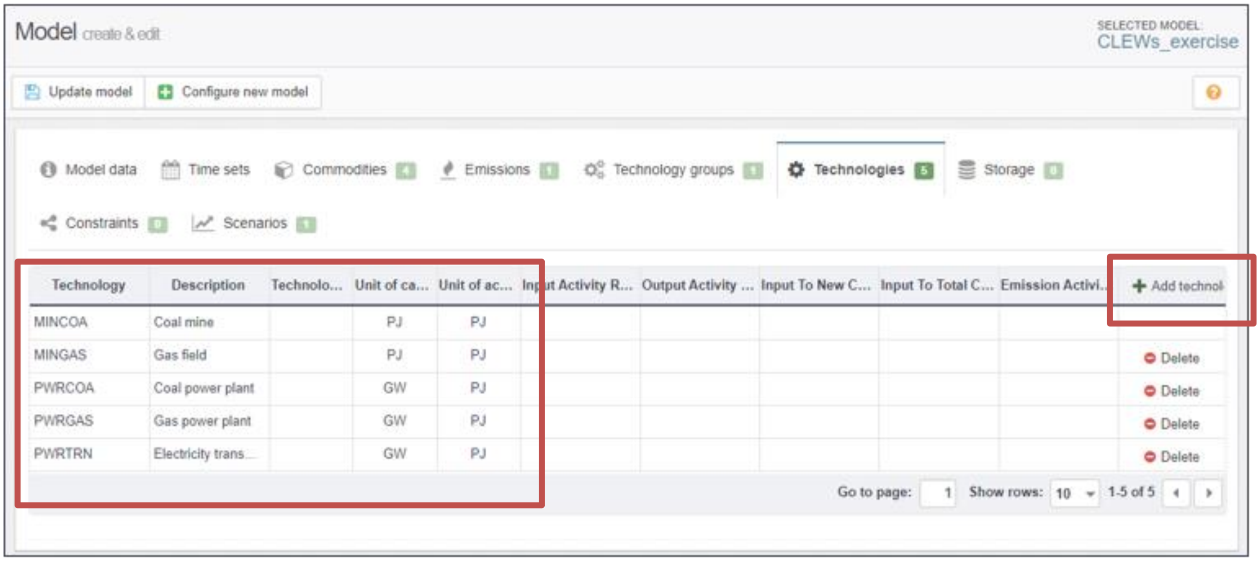


11. Click on "Update model" to save your edits.

12. In the “Configure model” window, select the “Technologies” tab to create 5 technologies (boxes in the RES) by changing the name of the default technology and adding 4 others using the “+ Add technology” button to the right.

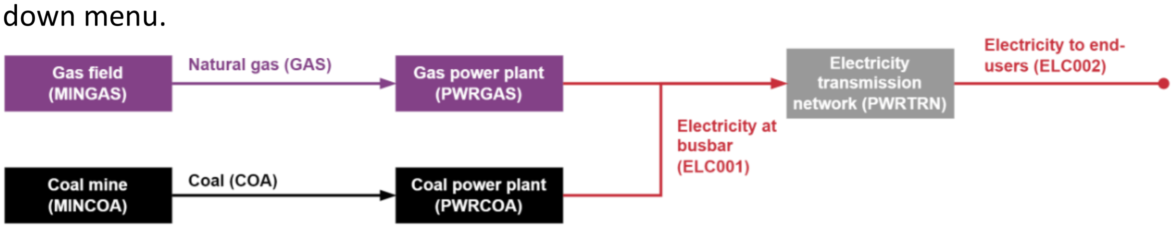


Use the technology names, descriptions and units below:



13. Save changes by selecting "Update model".

14. Specify the input commodity for each technology, as per the RES, by selecting the relevant commodity in the drop-down menu under "Input Activity Ratios" and specify the output commodity by selecting the relevant commodity in the "Output Activity Ratios" drop-down menu.



Example: COA is an output of technology MINCOA and an input to technology PWRCOA

The technology tab should be filled in as follows:

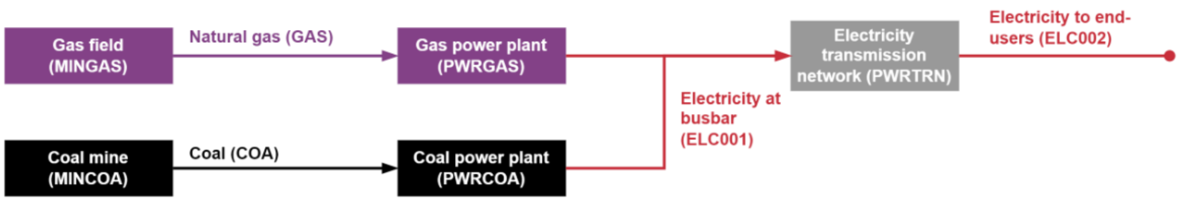
Technology	Description	Unit Capacity	Unit Activity	Input Activity Ratio	Output Activity Ratio
MINCOA	Coal mine	PJ	PJ		COA
MINGAS	Gas field	PJ	PJ		GAS
PWRCOA	Coal power plant	GW	PJ	COA	ELC001
PWRGAS	Gas power plant	GW	PJ	GAS	ELC001

PWRTRN	Electricity transmission network	GW	PJ	ELC001	ELC002

In the table, insert the input and output commodities in the cells' Input activity ratio' and 'Output activity ratio.' These are needed to create links between the technologies. I.e., to define which commodities flow in and out of which technologies to create an energy supply chain. For your convenience, the supply chain you will create is shown again in the figure below.

For all the technologies, the unit of capacity must be GW, and the unit of activity must be entered as PJ.

***Note:** Please disregard the "unit change warning" that appears in the interface when switching between the default MW to GW for capacity.*



This chain indicates that (starting from the right): there is an electricity demand (ELC002); this electricity is supplied to the consumers through the transmission and distribution network (i.e. it is an **output** of PWRTRN); gas power plants (PWRGAS) and coal power plants (PWRCOA) are the two technologies supplying electricity for transmission (ELC001) to the network (i.e. ELC001 is an **output** of those two and an **input** to PWRTRN); for supplying the electricity, the gas power plants are fed with natural gas (GAS) and the coal power plants with coal (COA); gas and coal come from extraction activities, respectively represented by MINGAS and MINCOA.

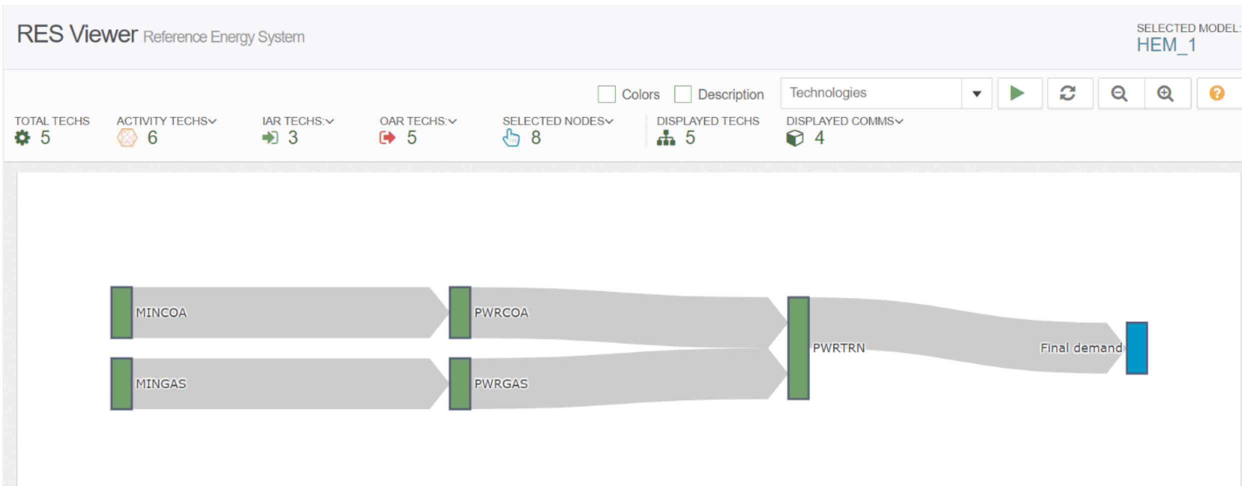
In OSeMOSYS, the supply chain must always start with technology. I.e., there must be a technology making the needed commodity available. In this case, at the start of the supply chain, two technologies represent gas and coal extraction. ***Failing to start a supply chain with a technology will mean the supply chain will not work, and the model will crash.***

With these steps, you have introduced new technologies and commodities into the model and created links between technologies, i.e., how the commodities flow between the different technologies. We must define the parameters that assign the link between technologies and commodities.

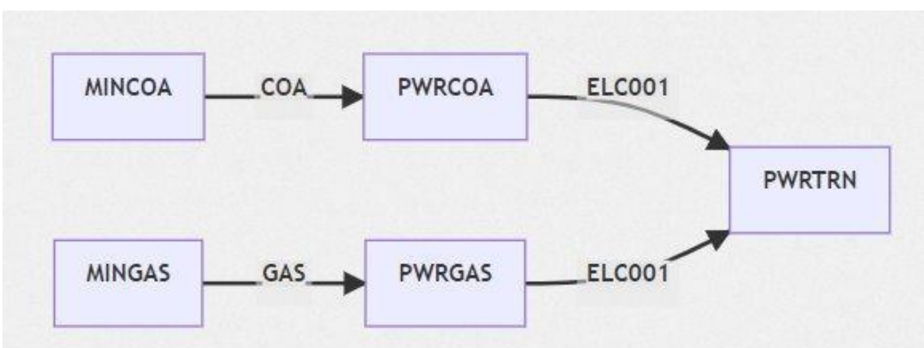
15. Save changes by selecting "Update model". ***(always do it, at the end of any step, with any element you modify!)***

16. At this stage, you can visualize the RES with the elements created. Go to "Model Diagram" on the left-hand side menu.

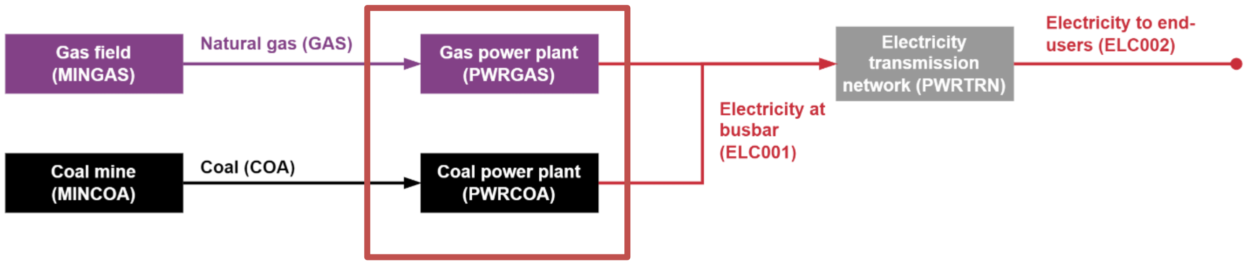
There is a **"Dynamic" view**, where technologies, inputs and outputs are identified. However, yours will not show the final demand yet, as you have not added it!

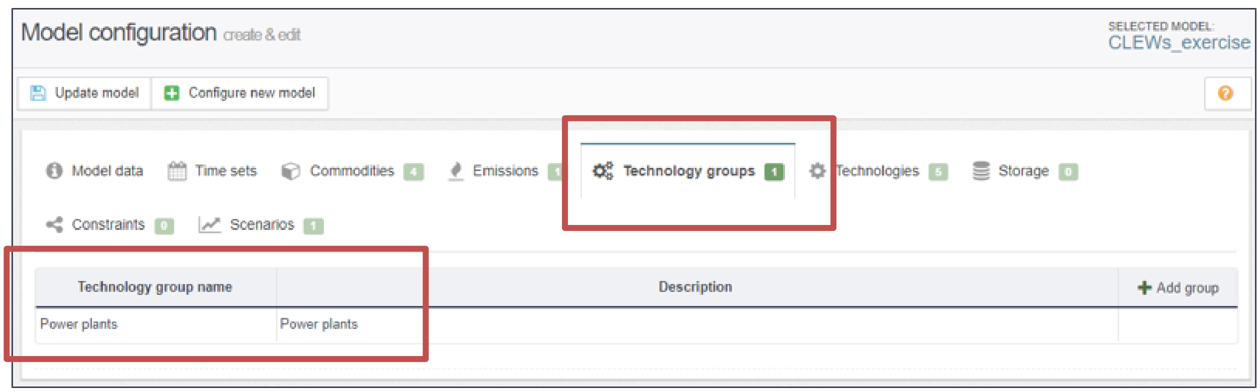


There is a **"Simple" view** similar to the sketched RES above.



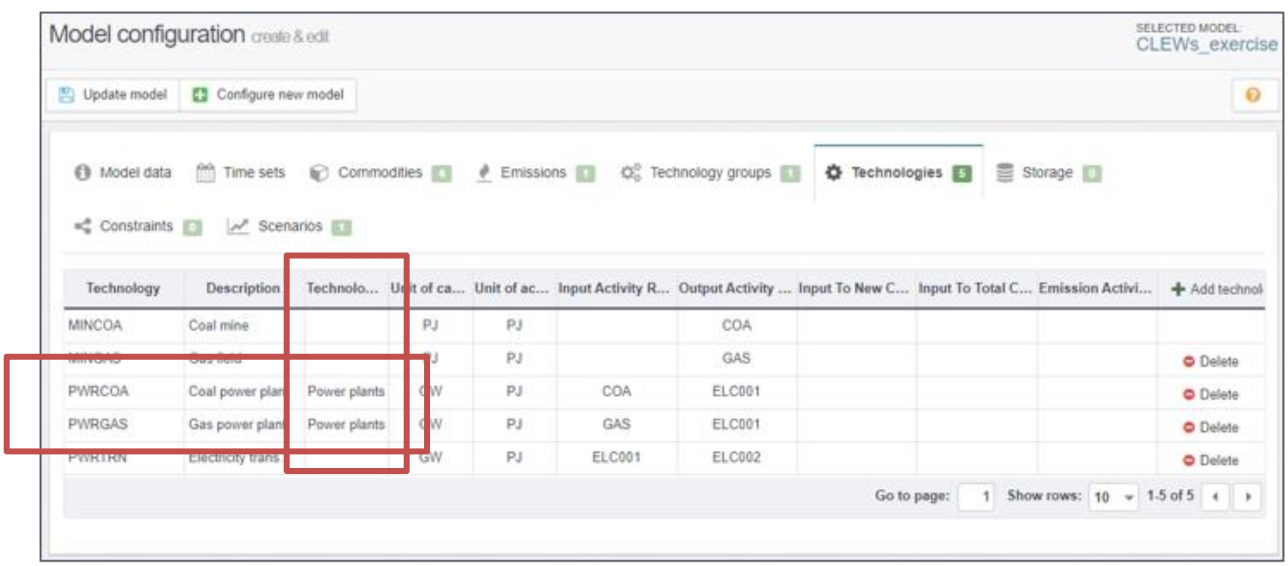
17. In the window "Define model configuration", select the tab "Technology groups" to create one group to represent power plants. Name it "Power plants".





18. Save changes by selecting “Update model”. *(**always do it, at the end of any step, with any element you modify!**)*

19. Go to the tab “Technologies” and assign the group created (“Power plants”) to PWRCOA and PWRGAS. Save changes (“Update model”).



20. Determine the value of the "Input and output activity ratios" to be added to the respective parameters.

To define the links between technologies and commodities, it is helpful to introduce some concepts/terminology used in OSeMOSYS:

- **Activity:** it refers to any process occurring within a technology (e.g., fuel combustion, water treatment, crude oil refining, crop harvesting, etc.)
- **InputActivityRatio:** or **IAR**, the ratio between an input commodity and technology activity (it is used to define which commodity is an input to a technology and with which efficiency)
- **OutputActivityRatio:** or **OAR**, is the ratio between an output commodity and technology activity.

Consider the following efficiency for the power plants:

- PWRGAS: 50%
- PWRCOA: 33%

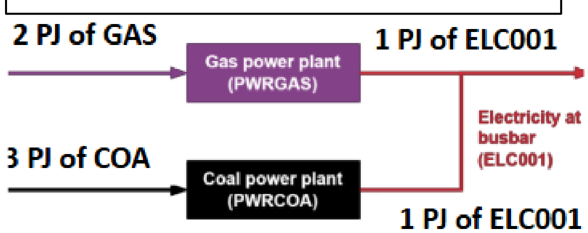
The efficiency of the process of electricity generation for Power Gas is the ratio between the output and the input. In this case:

$$Efficiency = \frac{1\ unit\ of\ electricity}{2\ units\ of\ Gas} = 50\%$$

If the output and the input have the same unit type (e.g., PJ), the efficiency will be a ratio with no unit. If the output and the input have different types of units, then the efficiency will have units. You choose the units. We will always indicate the exact values you need to input for the labs and in which units they are intended.

N.B. When defining the InputActivityRatio and the OutputActivityRatio, **you automatically define the efficiency of the technology**. See the example below:

PWRGAS efficiency = 50%
Input activity ratio = 1 / 50% = 2
2 PJ of GAS generate 1 PJ of ELC001



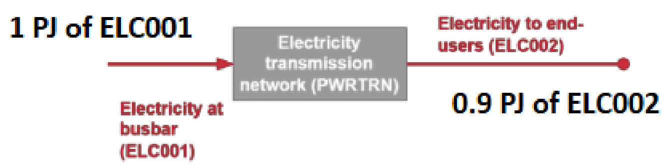
PWRCOA efficiency = 33%
Input activity ratio = 1 / 33% = 3
3 PJ of COA generate 1 PJ of ELC001

NOTE: Conversion efficiencies are determined by the relative magnitudes of the input and output activity ratios.

Example: 33% efficiency can either be represented as an input activity ratio of 3 and an output activity of 1 or as an input activity ratio of 1 and an output activity of 0.33

The main difference would be the relationship to the activity and capacity of the technology. For technologies where the activity/capacity is usually defined by the potential to produce an output (e.g. a power station), the output activity ratio should be set to 1, while for technologies that are usually defined by its potential to process an input (e.g. oil refineries and transmission lines) the input activity ratio should be set to 1.

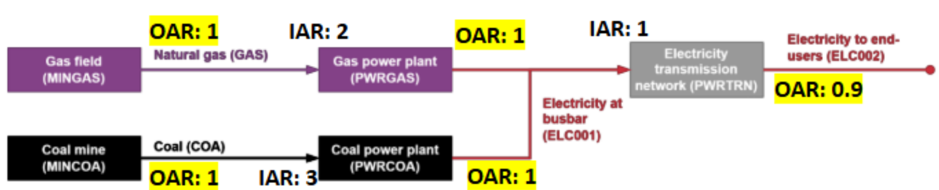
Consider 10% losses in the electricity transmission network.

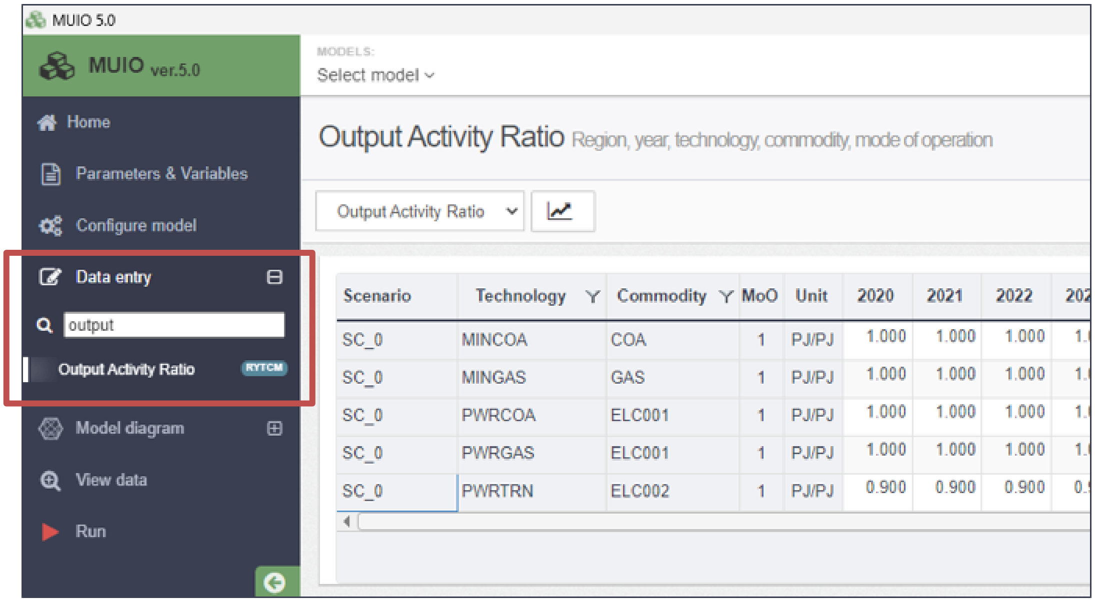


PWRTRN output = Input – losses/100%
Input activity ratio = 1
PWRTRN output = 1 – 10%/100% = 0.9

Add the values of the Output Activity Ratio in “Data entry” for the “Output Activity Ratio” parameter, as calculated above (and summarised in the figure below for your convenience).

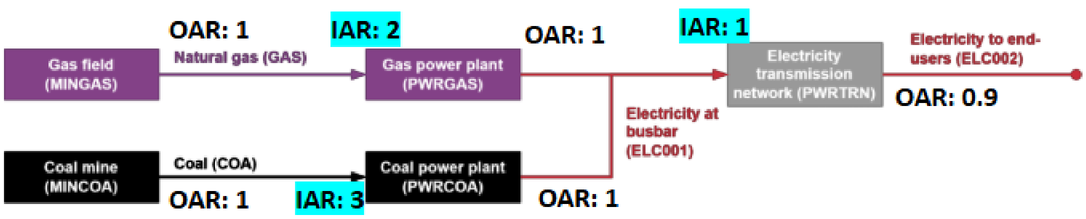
Click on “Save data” -> Be sure to save your work after every update to avoid losing any progress!

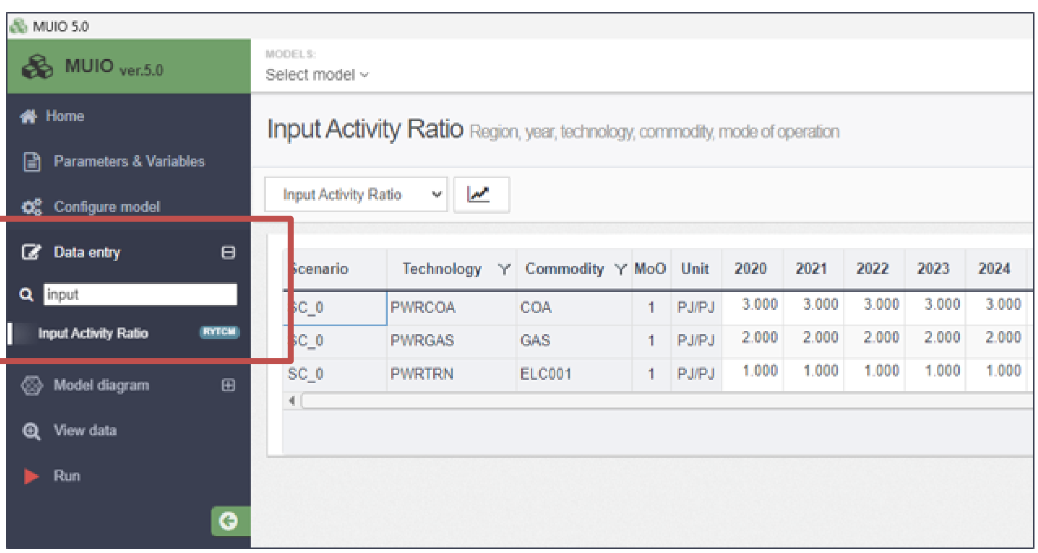




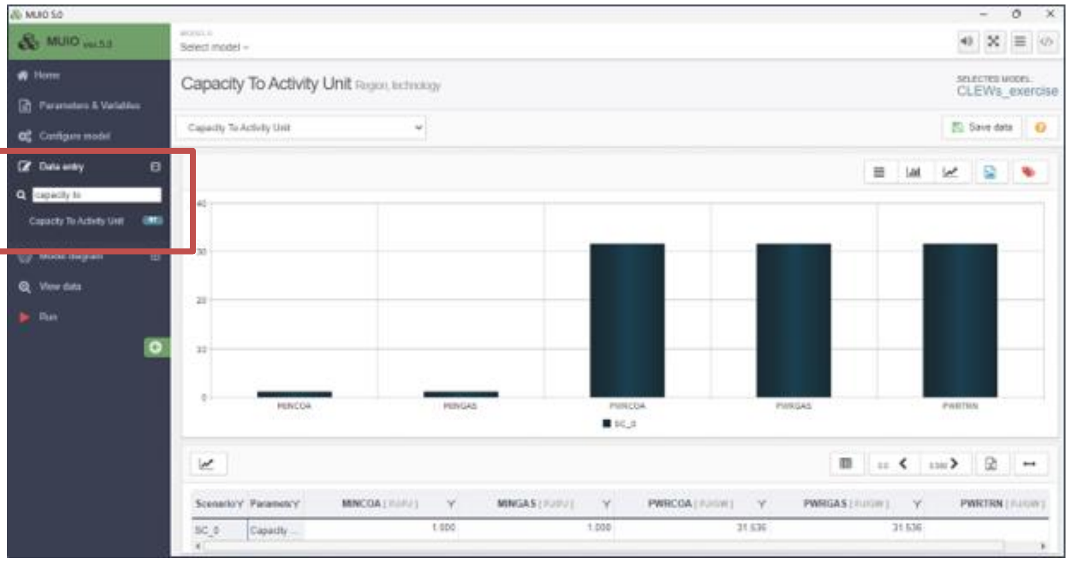
Add values for the Input Activity Ratio in "Data entry" for the "Input Activity Ratio" parameter, as calculated above and summarised in the figure below for your convenience.

Click on **"Save data"**. *(*Be sure to save your work after every update to avoid losing any progress!)





21. Add parameter data in “Data entry” for a new parameter, **“Capacity to Activity Unit”**. Change the default value in PWRCOA, PWRGAS, and PWRTRN to 31.536. Click on **“Save data”.**



NOTE: 31.536 corresponds to the energy, expressed in PJ, which can be generated or transferred by an electricity system technology with 1GW capacity and 100% efficiency in one year.

*i.e. 1 GW * 8760 h/year = 8760 GWh*
Since 1 W = 1 J/s and 1h = 3600s,
*8760 G *J/s *3600s = 31 536 000 GJ = 31.536 PJ*

22. **You are now finally adding a final demand for energy…** Add parameter data in “Data entry” for the “Accumulated Annual Demand” parameter.

    If you have not done already, go to this link and download the “**CLEWs OU November 2025 Data File.xlsx**”. Then open the file and, on the sheet “2. Assumptions”, go to line #225, and find the annual electricity demand (commodity ELC002). Copy and paste those values in “Accumulated Annual Demand” in the User Interface, in the line corresponding to ELC002.

NOTE on copying-pasting from the Excel file: You can select all the values of demand in row #218 on the Excel sheet (Ctrl + C), copy them all together, then on MUIO click only on the 2020 cell for ELC002 and paste (Ctrl + V). This way, you do not need to copy-paste or manually enter one value at a time!

In OSeMOSYS, demands are user-defined (exogenous) and can be set for one or more commodities. They "drive" the optimization process; the model's objective is to minimize ***the cost*** of meeting them.

The user can introduce two types of demand in OSeMOSYS:

- **AccumulatedAnnualDemand:** it must be balanced by the supply on an annual basis
- **SpecifiedAnnualDemand:** it must be met based on a "time-of-use" profile, such as daily fluctuations in electricity demand.

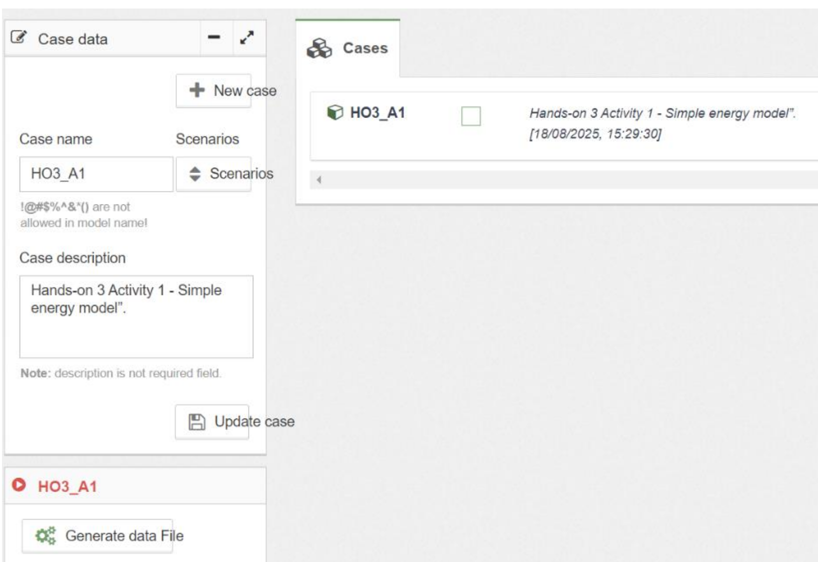
You will learn more about their differences in the following exercises. For now, you will introduce values only for the **AccumulatedAnnualDemand**. In this way, you will define a demand value for each year of the time domain. The supply chain needs to meet this demand over the year, without minding when it was exactly during that year.

23. Click on **“Save data”**. Time to run the model… :O

Activity 2 – Running the Model

Suppose you have carried out all the above steps correctly. In that case, you are now ready to run the optimization and see which technology or technologies will be chosen to meet the electricity demand. At this stage, we have given very little input. Therefore, the optimization will be unlikely to give meaningful results. However, it is good to go through the process of running a model, check if the run is completed, and understand how to read the results. The model can be run within MUIO. To run the model and visualize the results, take the following steps:

1. The model can now be run. To do so, create a “Case” by selecting “Run” in the left-hand side menu.
2. Name the case “HO3” and describe it, something like, “Hands-on 3 Activity - Simple energy model”.
3. Select “Create Case”.

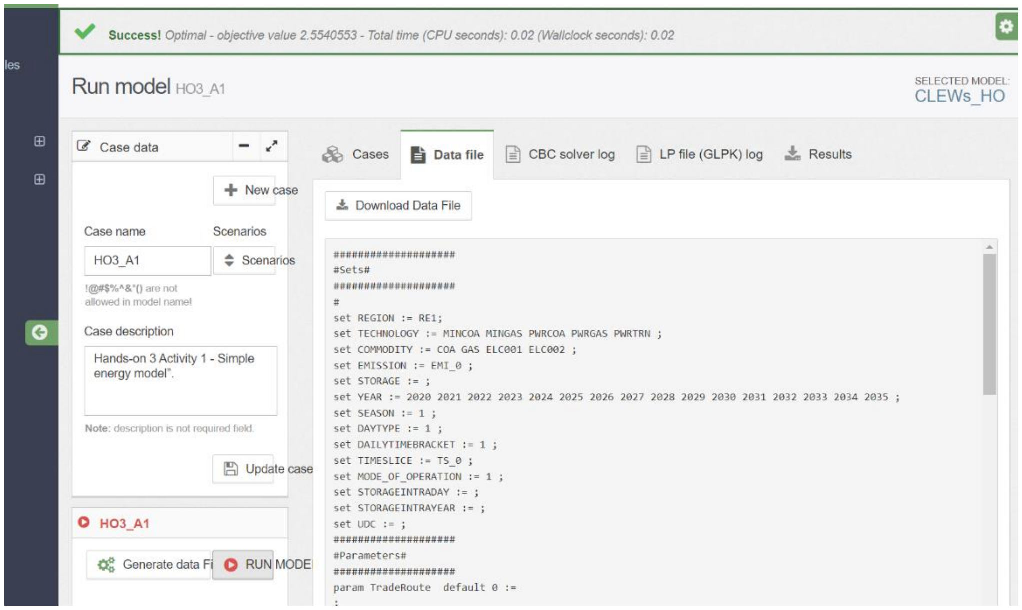


4. Before running the model, run the script to check for potential inconsistencies in parameter data, by clicking on the arrow symbol, to the left of the trash icon, for the selected case.

   After running the model, you will see several tabs on the right panel, in which you can check the solver log, the lp file, and all the results as a 'CSV' file.

5. The data file is generated, and a preview is shown in a new tab next to “Cases” named “Data file”. To run the model, click the button “RUN MODEL” shown at the bottom of the “Case data” window.

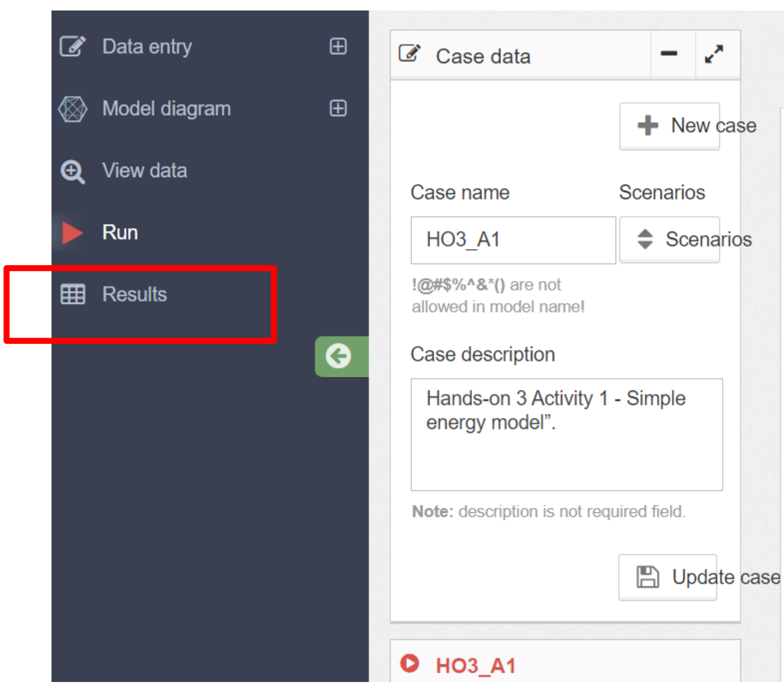
6. If the model run is successful, a **“Success”** message is shown at the top of the window, with the corresponding **“Run message”** at the bottom right corner. More tabs will be displayed after **“Cases”** and “Data file”, i.e., **“CBC solver log”**, **“LP file log”**, and **“Results”**.



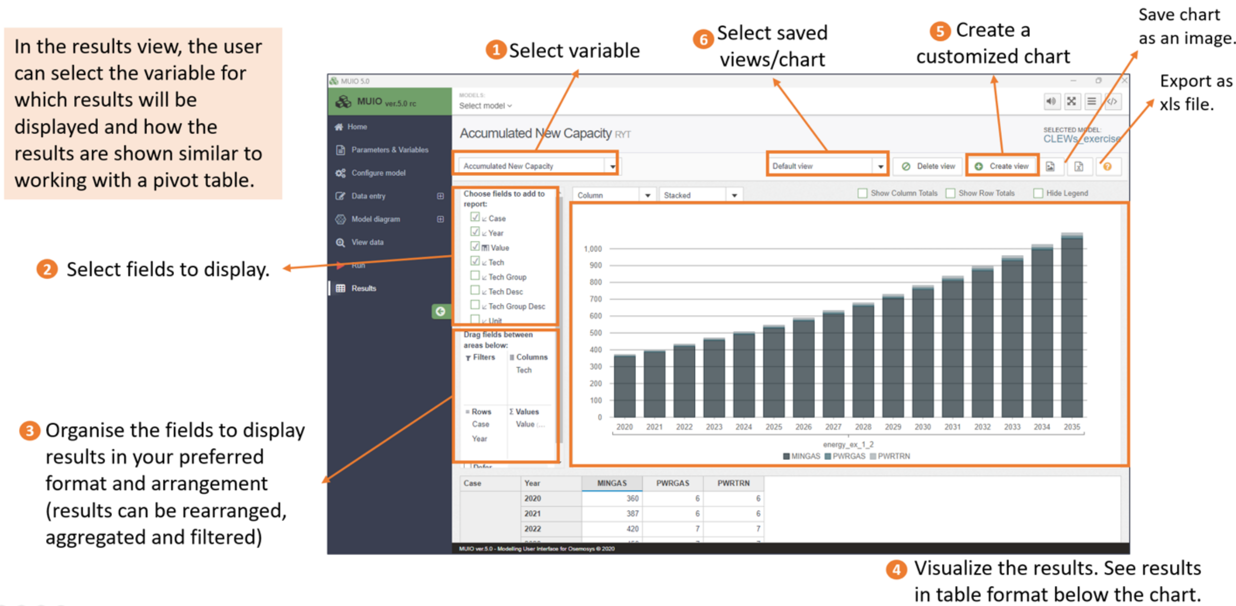
7. The data file, logs and results are downloadable and can be used outside the interface.

   Note that after exiting this view, the logs will not be displayed again if you select the case – only the tabs "Cases", "Data file" and "Results" will remain.

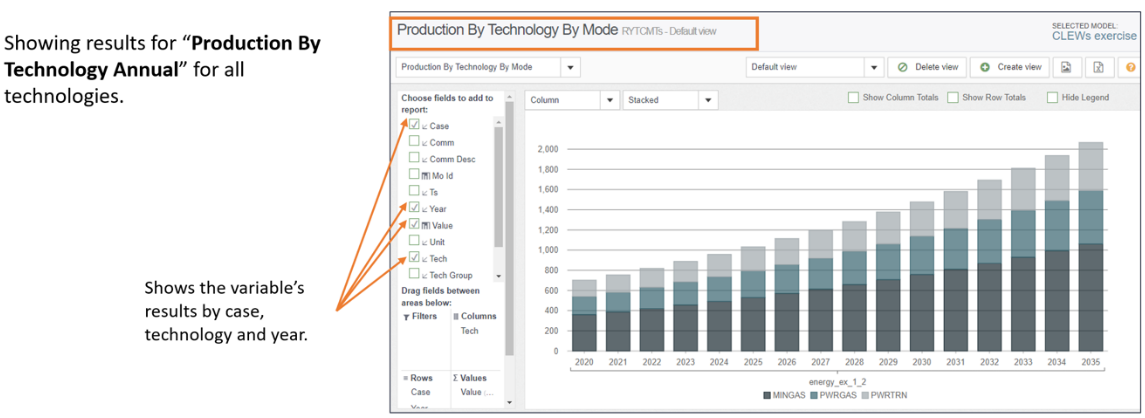
8. To visualize the results, select "Results" in the left-hand side menu.



The figure below gives you an overview of what you can modify on the results view for a specific variable.



9. We will now give you an example of how to visualize the results for a specific variable, in this case, “Production By Technology By Mode”. You may follow similar steps to view the results for other variables that will be useful for answering the questions at the end of the various exercises.

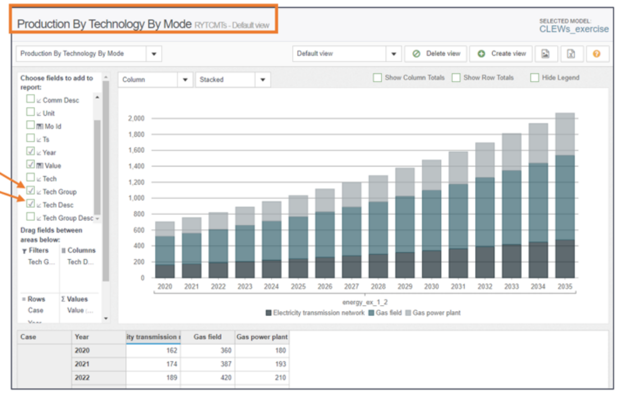


NOTE: Below the chart, results are displayed in a table format; the variable results table can also be exported.

10. Just for your information (as it may be very useful later on), we show you how to visualize the results for the variable "Production By Technology By Mode" ***for power plants only***.

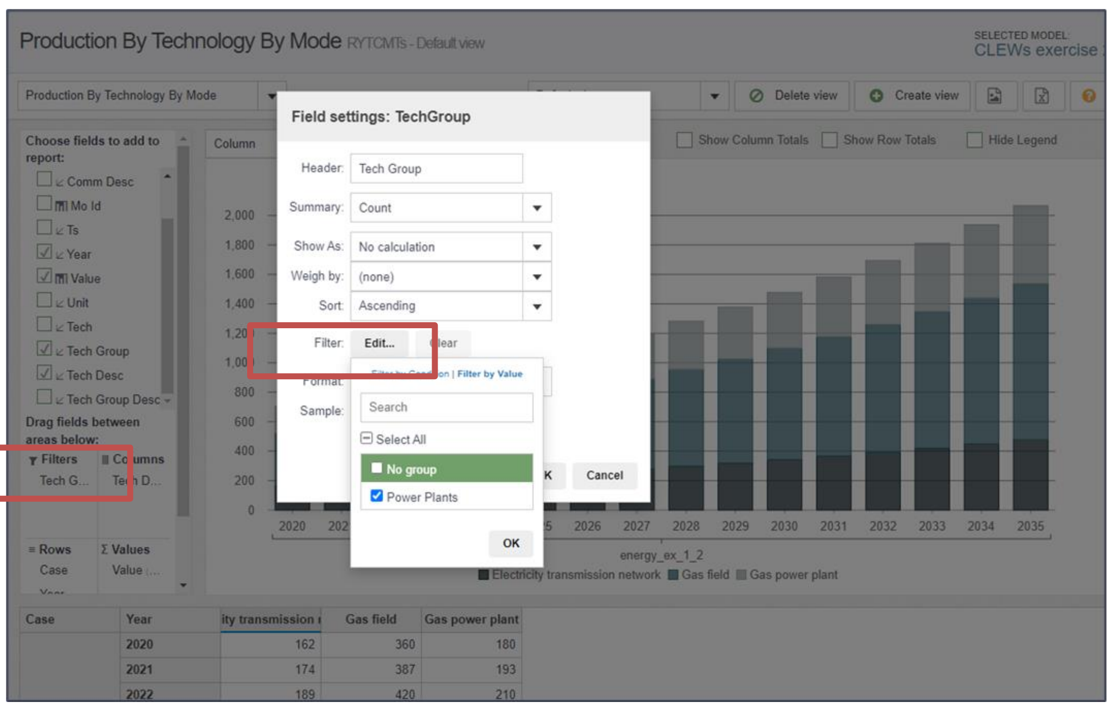
Variable: Production By Technology By Mode

- **Filters:** Drag "Tech group" to filters
- **Columns:** Select "Tech Description" and remove "Tech".



11. Right-click on "Tech Group" to select the group to display in "Field settings".

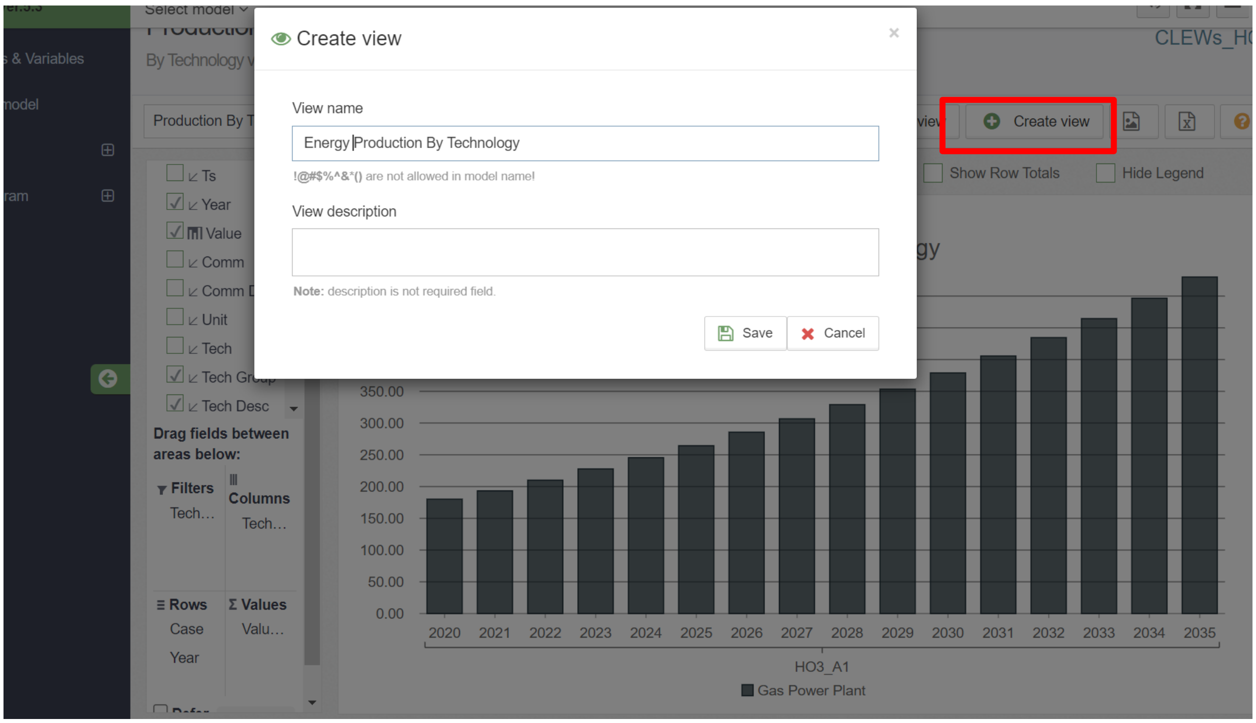
12. Leave "Power Plants" selected by removing the selection from "No group".



The results for "Production By Technology By Mode", displayed in the figure for the group "Power Plants", correspond to the generation by power plants over the modelling period.

You can save this graph you just created (and its settings), so that you can bring it up again any other time without having to redo all the settings. The graph will also be there when you run new cases, so that you can immediately see how the results change in the new cases.

In the top bar, towards the right, click on **Create view**, then give it a name (and a description if you wish), and click **Save**.



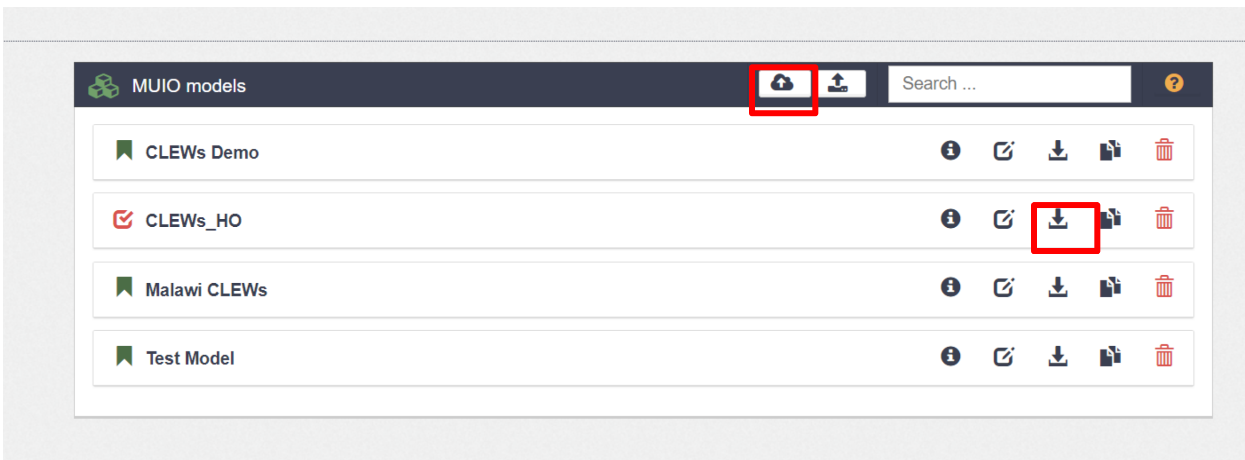
13. Another variable that may be of interest for answering the questions in the exercise is the “Use By Technology By Mode”, which shows how much input the various technologies are using (in activity units, in this case energy units, PJ). In our case, you can use it to see how much fuel (in energy units) the power plants are using, or how much electricity is entering the Transmission and Distribution grid.

HOW TO SAVE YOUR MODEL

A) When you have created a model, and before you make any other major changes that may break it, **it is good practice to save it safely on your laptop**, so that you may upload it again on MUIO if things go wrong. That is, you may want to do a **backup**.

To back up a model, go to the **Home** screen and click on the download icon to the right of its name. This will download the model itself, as a zipped folder. **Do not unzip the folder and do not change its name**. Store it safely in a place of your choice.

B) On the other hand, if you have models previously backed up (or models of colleagues) and you want to upload them to the interface, click on the 'restore' icon in the top bar of the **Home** screen. Click into the window that opens and navigate to the folder where you have the model (the zipped folder). Select the model and click 'open'. This will load the model onto MUIO.



C) For all the times you are asked to run the model in the next exercises, you will have to repeat all the related steps described above (we suggest you give your cases/models meaningful names so that you can distinguish all steps from each other).