



**MODULE:  
ENERGY SYSTEMS  
DYNAMIC MODEL**

Hands-on exercise

Developed in collaboration  
with: KTH-dESA

**Understanding Modelling Tools for  
Sustainable Development**

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## INTRODUCTION

This training exercise illustrates some basic features of energy systems modelling using OSeMOSYS and its interface MoManI with country data for Uganda. The focus is on meeting the electricity demand of the residential sector (both rural and urban) and other sectors (including commercial and industrial sectors). All data are extracted from the TEMBA model developed by KTH-dESA (Taliotis et al., 2016).

This training session is divided into three parts. The first exercise is to draft policy notes for Uganda's sustainable energy future, the second is to develop a new scenario to address climate change effects on electricity generation and electricity exports, and the last exercise is about introducing a new technology to diversify the electricity supply mix and improve energy security in the country.

All three exercises are supported by a pre-developed country model of Uganda using MoManI and detailed instructions to facilitate the training process.

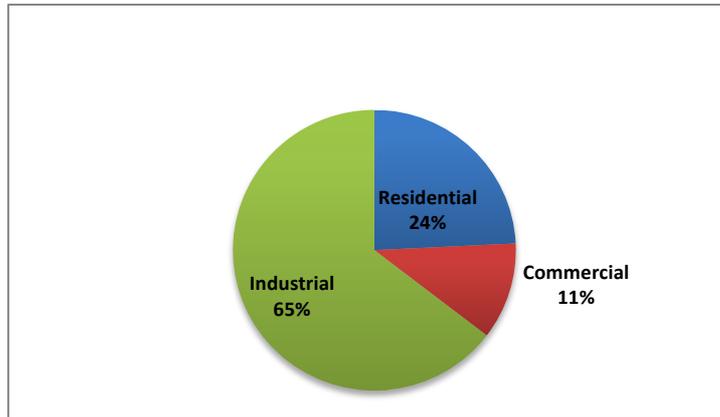
## CASE STUDY BACKGROUND

The Republic of Uganda is a landlocked country situated in East and Central Africa with a total area of 241,550 square kilometres. It is bordered to the east by Kenya, to the north by South Sudan, to the west by the Democratic Republic of the Congo, to the south-west by Rwanda and to the south by the United Republic of Tanzania.

Uganda has a total population of 38.8 million people; 15.8 per cent live in urban areas and 84.2 per cent in rural areas. Kampala, the capital, is the most populated urban area with 1.9 million people (United Nations, 2016). Electrification is an important challenge in Uganda; the national electrification rate is 15 per cent, which means that 31 million people lack access to electricity. The majority of this population lives in rural areas where the electrification rate is only 7 per cent. The situation is better in urban areas with a 55 per cent electrification rate (International Energy Agency, 2014).

The total electricity demand reached 2,070 GWh in 2013. The main consumer was the industrial sector (65 per cent), followed by residential (24 per cent) and the rest (11 per cent) goes to the commercial sector; see Figure 1 (Energypedia, 2015).

FIGURE 1: SHARE OF ELECTRICITY DEMAND BY SECTOR IN UGANDA (2013)



Uganda relies mainly on its massive hydro potential, with 84 per cent of its total electricity supply coming from hydropower and only 16 per cent from thermal power plants. Table 1: List of Main Power Plants in Uganda shows that main power plants in the country.

TABLE 1: LIST OF MAIN POWER PLANTS IN UGANDA

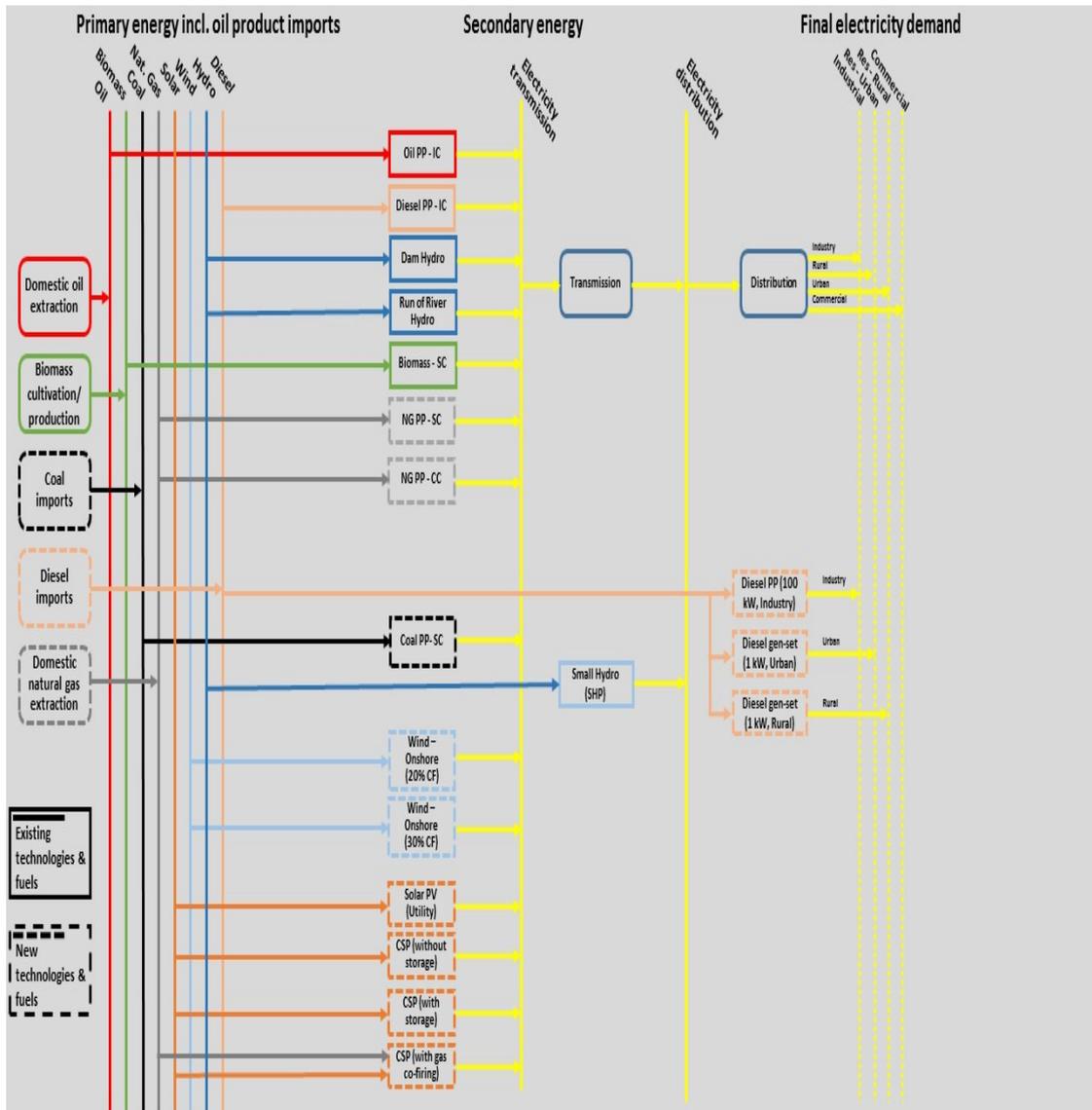
Plant/source	Capacity (MW)
<b>Kiira (large hydropower station)</b>	200
<b>Nalubaale (large hydropower station)</b>	180
<b>Bujagali (large hydropower station)</b>	250
<b>Jacobsen Namanve (thermal power)</b>	50

<b>plant)</b>	
<b>Electro-Maxx-Tororo (thermal power plant)</b>	50
<b>Kakira Sugar Works Ltd. (cogeneration)</b>	22
<b>Kinyara Sugar Works (cogeneration)</b>	7.5
<b>Kilembe Mines Ltd. (small hydro)</b>	5
<b>Tronder Power Bugoye (small hydro)</b>	13
<b>Eco Power Ishasha (small hydro)</b>	6.5
<b>Africa EMS Mpanga (small hydro)</b>	18
<b>Hydromax Buseruka</b>	9
<b>Kasese Cobalt Company Ltd.</b>	10.5

## REFERENCE ELECTRICITY SYSTEM

A reference electricity system is a schematic representation of the real electricity system in the region/country that is being modelled. It shows existing plants and flows as well as a portfolio of future options. The flow of energy is represented horizontally from resources on the far left, going through different transformation technologies, to reach final energy use on the far right. Figure 2 shows a reference electricity system for Uganda, which is used to develop the model in MoManI.

FIGURE 2: REFERENCE ELECTRICITY SYSTEM FOR UGANDA



## MODEL AND SCENARIOS

As mentioned earlier, a country model of Uganda was developed in MoManI to be used as a facilitating case study in this training exercise. The model takes existing technologies into consideration and provides for the installation of new technologies in the future.

Table 2 summarizes the economic and technical characteristics of the technologies used.

TABLE 2: TECHNOLOGY SPECIFICATION USED IN UGANDA MODEL

Technologies	Overnight capital cost (\$/kW)				Fixed cost (\$/kW)				Variable cost (\$/MWh)				Construction time				Life (years)	Efficiency	Load factor	
	2010	2012	2020	2035	2010	2012	2020	2035	2010	2012	2020	2035	2010	2012	2020	2035				
Diesel centralized	708	708	708	708	8	8	8	8	2	2	2	2	2	2	2	2	2	25	35%	80%
Diesel 100 kW system (industry)	659	659	659	659	-	-	-	-	55	55	55	55	1	1	1	1	1	20	35%	80%
Diesel 1 kW system (residential/commercial)	692	692	692	692	-	-	-	-	33	33	33	33	1	1	1	1	1	10	21%	72%
HFO	1350	1350	1350	1350	-	-	-	-	15	15	15	15	2	2	2	2	2	25	35%	80%
OCGT	708	708	708	708	8	8	8	8	2	2	2	2	2	2	2	2	2	25	30%	85%
CCGT	1021	1021	1021	1021	1	1	1	1	2	2	2	2	3	3	3	3	3	30	48%	85%
Coal	2080	2080	2080	2080	27	27	27	27	4	4	4	4	4	4	4	4	4	35	37%	85%
Hydropower large scale	1777	1777	1815	1929	22	22	22	24	4	4	4	4	4	4	4	4	4	50	100%	
Hydropower small scale	5127	5127	5075	5025	41	41	40	40	7	7	7	7	4	4	4	4	4	50	N/A	17%
Hydropower medium scale	1777	1777	1815	1929	26	26	26	26	5	5	5	5	4	4	4	4	4	50	100%	
Biomass	4447	4447	4325	4105	59	59	56	54	3	3	3	3	3	3	3	3	3	30	38%	50%
Nuclear	4480	4480	4480	4480	112	112	112	112	2	2	2	2	7	7	7	7	7	60	33%	85%
Geothermal	4898	4898	4769	4356	49	49	48	44	-	-	-	-	4	4	4	4	4	25	100%	85%
Wind onshore	1940	1940	1829	1743	37	37	34	33	-	-	-	-	2.5	2.5	2	1.5	1.5	25	N/A	Varies
Solar PV (utility)	1562	1562	1158	935	25	25	23	22	-	-	-	-	1.5	1.5	1.5	1.5	1.5	25	N/A	25%
Solar PV (residential/commercial)	1977	1977	1461	1175	33	33	31	29	-	-	-	-	1	1	1	1	1	25	N/A	20%
PV with 1 kWh battery	4258	4101	3079	2347	-	-	-	-	17.1	17.1	17.1	17.1	1	1	1	1	1	25	N/A	22.5%
PV with 2 kWh battery	6275	6053	4548	3459	-	-	-	-	19	19	19	19	1	1	1	1	1	25	N/A	25%
Solar thermal no storage	4988	4988	3677	2860	200	200	147	114	-	-	-	-	3	3	2.8	2.5	2.5	25	N/A	35%
Solar thermal with storage (6 hours, 12 hours, molten salt)	6777	6777	4074	3083	61	61	42	42	4	2	2	2	3	3	2.8	2.5	2.5	25	N/A	63%
Solar thermal with gas co-firing	1374	1374	1374	1374	-	-	-	-	16.4	16.4	16.4	16.4	3	3	2.8	2.5	2.5	25	53%	85%

In energy modelling, environmental aspects are important to consider in the analysis. Thus, in this exercise, carbon dioxide and nitrogen oxide emissions are taken into consideration. Table 3 summarizes emissions factor values for different type of fuels (United States, Energy Information Administration, n.d.).

TABLE 3: EMISSIONS FACTORS PER FUEL

Fuel	Mton/PJ
Diesel	0.0693
HFO	0.0747
Gas	0.0503
Coal	0.0893

Scenarios are used in energy modelling to study the effect of different policy plans and measures on the energy system. Scenario variations are usually compared to a reference, or **business-as-usual**, scenario. In this exercise, the following scenarios are developed:

1. **Business-as-usual or BAU** scenario, which is the reference scenario. It is assumed that Uganda will reach 100 per cent electrification by 2030, and that the annual energy intensity growth rate will match the East African power pool rate (International Energy Agency, 2014).
2. **Electricity export or EXP** scenario, which provides insights if the Government decides to start exports to neighbouring countries from 2020 onward. The export demand is subjected to gradual growth to reach a level of about 5,400 GWh by 2040.
3. **Climate change adaptation or CCA** scenario, which is generated to explore the effect of reduced rainfall and droughts on the electricity generation mix in a country where hydropower plays an important role.

## EXERCISES PER TARGET GROUP

## EXERCISE (1): SUSTAINABLE ENERGY POLICY NOTE

The goal of this exercise is to write a policy brief for Uganda to address the effect of climate change on electricity generation. In a group of three or four participants, you are asked first to analyse the modelling results shown in MoManI for the BAU and CCA scenarios. Then, based on your analysis, draft a policy brief following the tasks below:

## TASK 1

Use the instructions given in Appendix A to visualize the results in MoManI. You may need to look at variables such as:

- Production by technology annual
- Total capacity annual
- Capital investment
- Other variables (if needed)

## TASK 2

Describe in bullet points the 5 to 10 most important characteristics of Uganda's energy mix under the BAU scenario.

## TASK 3

Looking into the CCA scenario and comparing it with the BAU scenario, explain the changes that the model suggests will occur in the electricity system due to climate change.

Answer the guiding questions:

- Which technologies will be phased out?
- Which technologies will fill the gap?
- Which generation options are the main electricity producers?

(You can use the “compare scenario” functionality illustrated in Appendix B.)

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**TASK 4**

Analyse the “capital investment”, “annual fixed operating cost”, “annual variable operating cost” and “annual emissions” associated with the electricity generation mix under the **CCA scenario** and compare them with those resulting from the BAU scenario. What are your observations?

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**TASK 5**

Based on your analysis, write three to five short policy notes to support adaptation to climate change in Uganda. You may think about:

- Future technology investments
- Security of supply and resource availability
- Environmental impact

**EXERCISE (2): DEVELOPING A NEW SCENARIO**

This exercise touches on one of the important aspects of modelling, which is developing new scenarios. In a group of three to four participants, develop the new scenario in MoManI. This new scenario will study the combined effect of climate change and electricity export on the national electricity generation mix. The following tasks should be performed:

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**TASK 1**

Follow the instructions given in Appendix C to introduce a new scenario in MoManI. Clone a revision from the **CCA** scenario.

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**TASK 2**

Introduce the name and a description of the new scenario in MoManI. Let's call it the **CC+EXP scenario**. Write a brief description, such as electricity export under the climate change adaptation scenario.

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**TASK 3**

Change for the export fuel "**UGEL\_Export**." Change the input data for the parameter "specified annual demand" as shown in the data file, *Uganda\_data\_file.xls*.

---

**TASK 4**

Save all your changes and run the optimization. You can follow instructions given in Appendix E.

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**TASK 5**

Visualize and analyse results of the new scenario and compare them with the BAU scenario. You may look at the variables named "ProductionByTechnologyAnnual", "TotalCapacityAnnual", "CapitalInvestment" and "AnnualEmissions".

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**TASK 6**

What are your observations?

**EXERCISE (3): INTRODUCING NEW TECHNOLOGIES (OPTIONAL)**

This exercise will move you to a more detailed level in the modelling process. In this exercise, you are asked to introduce new technologies that contribute to the electricity supply mix in Uganda. This will require the implementation of necessary changes in all parameters associated with the new technology before running the optimization. The following tasks should be performed:

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**TASK 1**

The new technology is “**Geothermal Power Plant**”.

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**TASK 2**

Use the MoManI instructions (Appendix D) to introduce the new technologies to the existing list of technologies. Follow the same name and description given in Appendix D.

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**TASK 3**

Use *Uganda\_data\_file.xls* to add the necessary data for this new technology. Remember that each technology has economic and performance characteristics that need to be defined in the modelling process (e.g., capital cost, efficiency, capacity factor, constraints, etc.).

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**TASK 4**

Save your work, run the simulation and compare your new results with the BAU scenario. You may look at the variables named “ProductionByTechnologyAnnual”, “TotalInstalledCapacity”, “CapitalInvestment” and “AnnualEmissions”.

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**TASK 5**

What are your observations?

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**APPENDIXES**

## APPENDIX A

## INSTRUCTIONS TO VISUALIZE RESULTS IN MOMANI (EXERCISE 1)

1. Open your web browser and navigate to <http://momaniweb.com>.
2. Click on “Results” from the top tabs.
3. From the list of models, click on “View Scenarios” next to “**Uganda-Group X**”, where “X” is the number of your group. This will lead you to all scenarios developed for this model.
4. You should be able to see three scenarios:
  - a. BAU
  - b. EXP
  - c. CCA
5. Click on “View Results” next to “Scenario: **BAU**” to go to the list of all output results available for this scenario.
6. The results for each variable available in the scenario can be viewed on the interface by clicking on “View Charts”; otherwise, you can click “Download csv” to obtain the results offline. For this example, click on “View Charts” for the variable **ProductionbyTechnologyAnnual**.
7. The default setting in MoManI generates results for all technologies. However, we need to filter data by technology by clicking on the drop-down list under “**Group by**” and selecting “**Technology**”.
8. Then you need to simplify the graph:
  - a. Click on “Show Additional Settings”.
  - b. Under “Display data for:” unclick “Import\_and\_Extraction” and “Trans\_and\_Dist”.
  - c. Finally, scroll up and click on “Hide Settings”.
9. Now you can see only the power plants’ generation; remember that generation units are (PJ = 277.777778 GWh).
10. Similarly, you can view results for other variables and other scenarios to perform the required analysis for your policy brief.

## APPENDIX B

## INSTRUCTIONS TO COMPARE RESULTS OF TWO SCENARIOS IN MOMANI

1. Open your web browser and navigate to <http://momaniweb.com>.
2. Click on “Results” from the top tabs.
3. From the list of models, click on “Compare Results” next to “**Uganda-Group X,**” where “X” is the number of your group. This will lead you to a new page called “Comparing results for Uganda” where you will see three drop-down lists.
4. Select which scenario you want to appear on the left side of the page by clicking on the first drop-down list under “Left scenario”. It is recommended to keep this as the reference scenario, in this case, BAU.
5. Similarly, select which scenario you want to be on the right side of the page by clicking on the drop-down list under “Right scenario”. For example, select EXP.
6. Then you need to select which variable you want to compare between the two scenarios. Click on the third drop-down list and select, for instance, the variable “**Demand**”.
7. MoManI will generate two graphs for the selected scenarios: in this case, BAU left and EXP right. Notice that we have higher demand for the second scenario, which is due to additional electricity demand for export.
8. Both graphs can be segregated using the “Group by” option. And to filter output results and/or arrange legends; click on “Show additional settings”. See instructions in Appendix A.

## APPENDIX C

## INSTRUCTIONS TO DEVELOP A NEW SCENARIO IN MOMANI (EXERCISE 2)

1. Open your web browser and navigate to <http://momaniweb.com>.
2. From the list of models, click on “Scenarios” next to “**Uganda-Group X**”, where “X” is your group number. This will lead you to all scenarios developed for this model. You should be able to see three scenarios:
  - a. BAU
  - b. EXP
  - c. CCA
3. Click on “Clone Revision” next to “Scenario: **CCA**” to create a new scenario that inherits data from the CCA scenario. It might take few seconds before you see the new scenario.
4. You will notice that a new scenario is added to the list with the same name as the original scenario that it was cloned from, in this case, **CCA**. To edit the name, click on “Enter Data” next to your new scenario. This should lead you to a new page, “Entering scenario data”.
5. Write the name and description for your scenario, then click “Save”. In our case, for consistency between the groups, please name the new scenario as “**CCA+Elect.EXP**”. The description will be “Electricity export under the climate change scenario condition”.
6. Scroll down to the parameter “**SpecifiedAnnualDemand**” and click on “Enter data – slices”. This will take you to a new page to enter data for the selected parameter.
7. To be able to generate the table, click on the drop-down list next to “Fix dimensions” and select “Region”. This will generate the required table with different “Fuels” (commodities) as rows and “Years” as columns.

Use the data given in **Uganda\_data\_file.xls** to add data for the export fuel “UGEL\_Export”. Finally, click “Save”.

## APPENDIX D

## INSTRUCTIONS TO ADD A NEW TECHNOLOGY IN MOMANI (EXERCISE 3)

1. Open your web browser and navigate to <http://momaniweb.com>.
2. From the list of models, click on “**Edit Set Data**” next to “**Uganda-Group X**”, where “X” is your group number. This will lead you to a new page where you can find all “Set”<sup>1</sup> data.
3. Scroll down to “Technology” and click on “Enter Data” to add a new technology.
4. Click on (+) to add a new field for a new technology. Then write the name and description of the new technology as shown below. Finally, click “Save”.

#	Name	Description
1	UGGOCVP00	Geothermal power plant

5. To make sure that the technology is properly linked in the model, you need to enter data for “Input Activity Ratio” and “Output Activity Ratio”. Moreover, you must feed in the model inputs regarding the technical characteristics of the technology, like efficiency, capacity factor, etc.. Make sure you fill in the required data for the new technology. Use the data given in **Uganda\_data\_file.xls**. and the **MoManI user manual**.
6. Similarly, each technology should have some economics-related characteristics (capital cost, variable cost, etc.). Make sure you enter the required data for your new technology. Use the data given in **Uganda\_data\_file.xls**.

**Hint: If more detailed instruction is required, please use the MoManI user manual.**

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<sup>1</sup> “Sets” are constant across scenarios. They are groups of elements used to define the structure of the model. For example, “Regions” or “Years” are sets, and each region or year is an element of these sets.

APPENDIX E  
INSTRUCTIONS TO RUN OPTIMIZATION USING MOMANI  
(EXERCISES 2 AND 3)

1. After generating the model, the next step is to set up the solver that is used for running the optimization. Currently, MoManI uses GLPK, an open-source free solver. Download the GLPK solver according to the instructions you received via email.
2. Going back to our model in MoManI, navigate to the scenario you want to optimize. For example, “Models > Uganda – Scenarios > BAU” and click on “**Download executable**”.
3. Open the downloaded folder. You will find three text files named data.txt, metadata.txt and model.txt, and an executable file. Double click on the executable file, **RunSimulation.exe**; this will open a new window. Click on “**Run**”.
4. This should run the selected scenario only. Two separate screens will appear, and you can see that the simulation is running to find the optimal solution for the given model configuration. If the optimal solution cannot be found, you should see an error message on this screen.
5. Once the simulation is finished successfully, and the optimal solution is found, the solver will upload results back to MoManI. It will also generate a folder called (**res**) with all result outputs in excel format (.csv) to be used in further analyses.

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