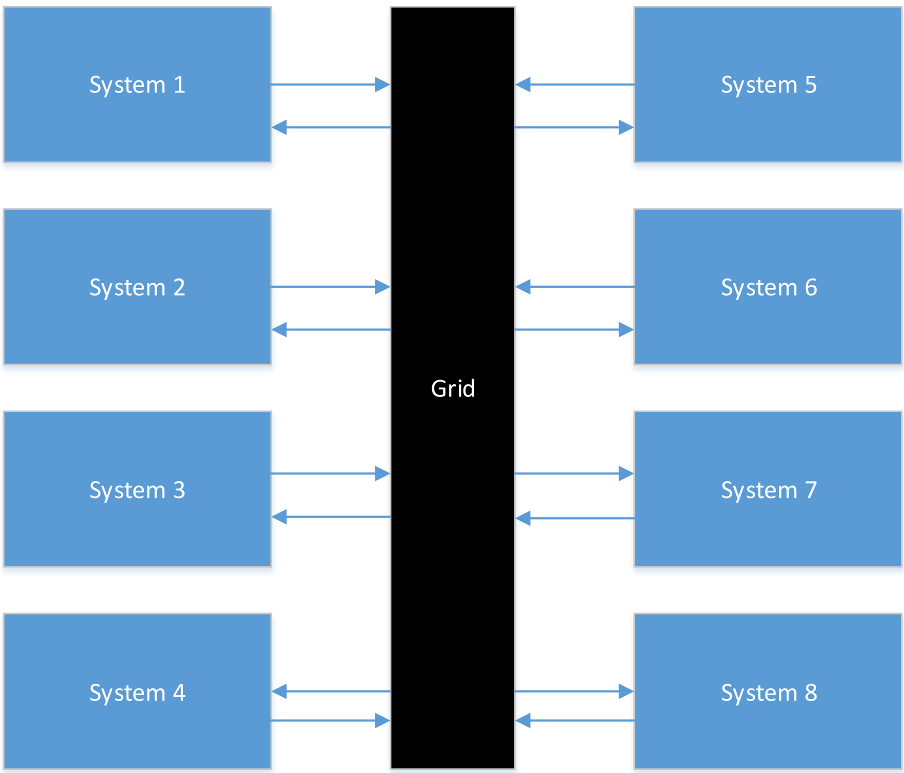
MultiNode v1 for EnergyPLAN

Documentation



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www.EnergyPLAN.eu

Preface

The MultiNode add-on tool for EnergyPLAN is developed as a central part of the PhD project "Energy System Analysis of Multiple Systems". The PhD is part of the Centre for IT–Intelligent Energy System in Cities (CITIES) Research Project funded by Innovation Fund Denmark. Besides, the tools draw on research and development related to EnergyPLAN, the 4DH Research Center also funded by Innovation Fund Denmark, and the various Heat Roadmap Europe Studies.

Jakob Zinck Thellufsen has done the main development of the tool, but with assistant and feedback from Henrik Lund, Prof. AAU, and Anders N. Andersen and Henning Mæng from EMD International.

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The MultiNode Concept in EnergyPLAN

The goal of the MultiNode Add-on Tool to EnergyPLAN is to be able to run and link several EnergyPLAN analyses. The concept currently only looks at the electricity sector and defines the link through cables. MultiNode has the possibility of linking between 2 and 28 different systems. These energy systems can be of all kind of sizes, meaning it is suitable to run both on local-national analyses and when linking multiple national energy systems, e.g. the European Union.

MultiNode is part of the current development strategy for EnergyPLAN. This means that instead of making radical changes to EnergyPLAN, the development goes towards creating add-on tools that utilizes EnergyPLAN as a base framework. Therefore, MultiNode does not make changes to the way EnergyPLAN runs. This is reflected in the overall concept of the MultiNode add on tool, as exchange possibilities have to be identified in a certain way.

Figure 1 shows the overall concept of the MultiNode add on tool. The figure illustrates how the tool identifies exchange options. First, MultiNode runs all selected energy systems without any interconnection. From this analysis, MultiNode identifies two sets of information for each system: 1) the hourly amount of exportable electricity and 2) the potential for electricity import every hour. MultiNode identifies a potential import demand as hours with:

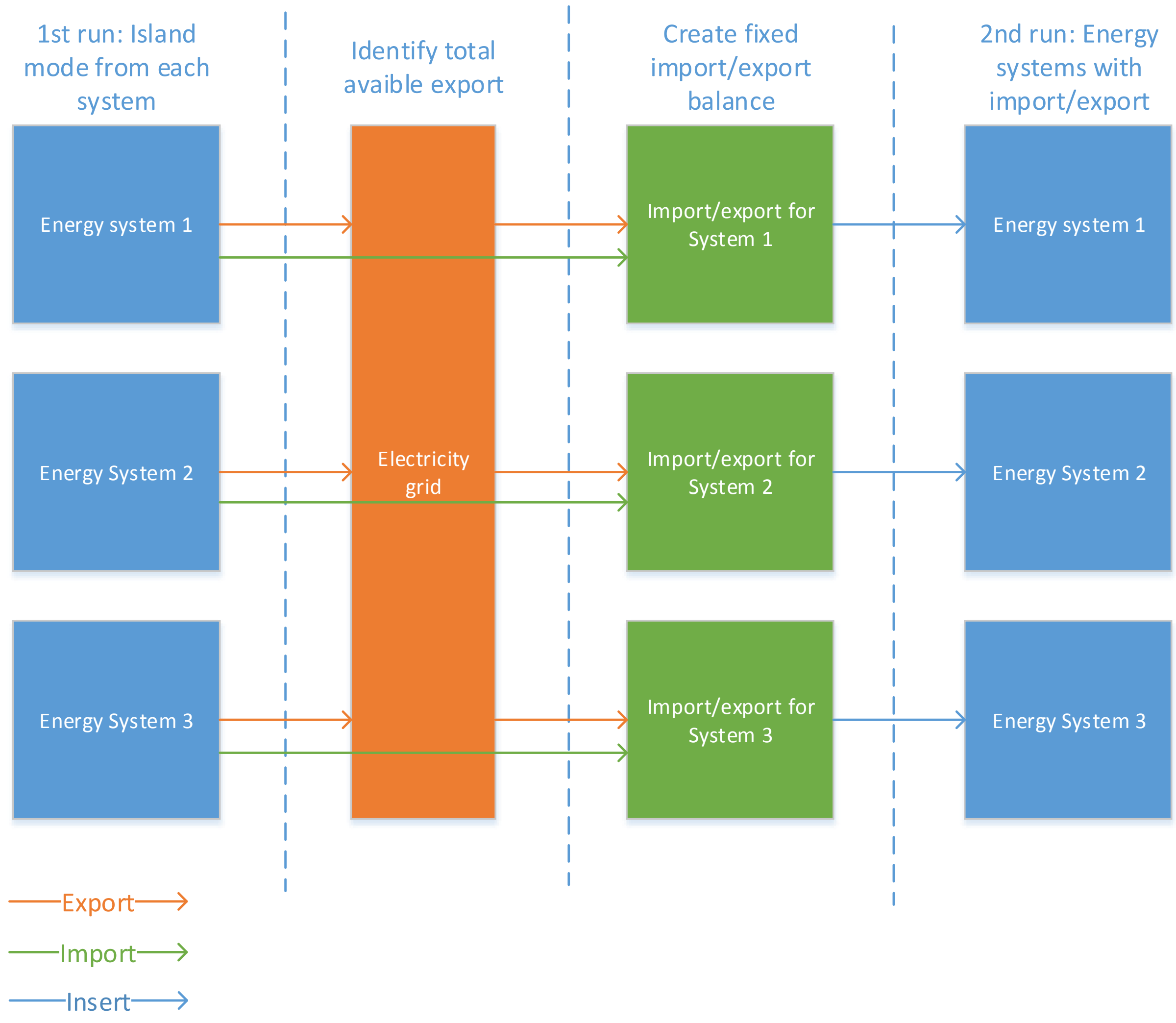
- Lack of sufficient capacity
- Hours with power plant production

From the information regarding the hourly available exportable electricity and hourly potential for importing electricity, MultiNode now tries to link the exportable electricity with the demand for import. In hours with import demand and available export, each system will try to fulfill its demand for import as much as possible. Each individual energy system will get access to the electricity available for import on the grid based on a merit order.

After utilizing as much of the exportable electricity as possible in each of the energy systems, an import/export balance is created for each energy system and the yearly net export is identified. Together, the balance and the net export identifies each system's interaction with the grid.

Note that the tool uses a total grid capacity for transmission since it views the electricity grid as one unison between all systems that has a defined grid capacity over zero.

Finally, the MultiNode add-on tool runs each of the selected energy systems again now with the information regarding import and export. Based on these simulation results the MultiNode has the option of summarizing all systems together.



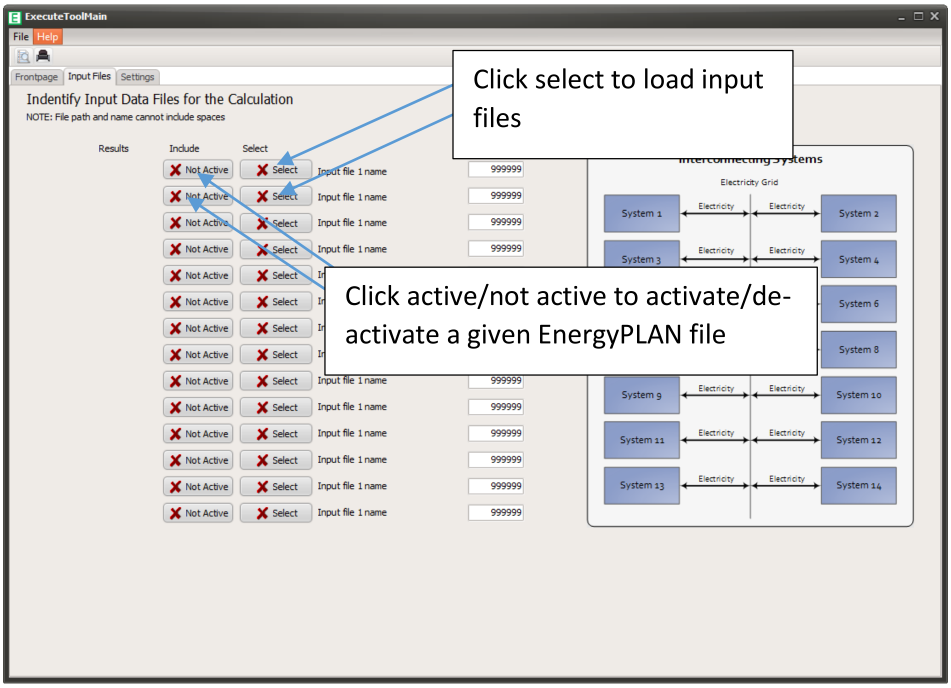
Using the MultiNode tool

MultiNode is structured in four tabs. The "front page" where the user defines the model and runs the different parts. The "input files" where the user defines the different energy plan systems. "Transmission" where the user defines transmission capacities and "settings" where the user defines energy units and RES sources.

When opening MultiNode the first screen is the front page. To run the model either use the automatic generation of country names (currently only works for EU28, the Nordic Countries, and the Baltic Countries). Be aware that to use this function you have to follow a certain naming standard. Else just leave these functions be, as they are not necessary.

The button for selecting operation mode defines the methodology for merit order in the system in terms of utilizing excess electricity. The standard procedure is to define the merit order based on the order of energy plan files in the input files tab. Otherwise, the tool can use the system priced calculated in each system to define merit order. Note that this requires that you have defined costs in each EnergyPLAN system. Be aware that the MultiNode tool does not check your cost assumptions and unit settings.

The following takes you through the tabs, to run your model successfully.

<table>
<tr>
<td>Go to input files and select the number of EnergyPLAN systems you want to connect.
Click select to load the files.
Click the “active” button to deactivate a file if you do not want to include it in a given analysis.</td>
<td>
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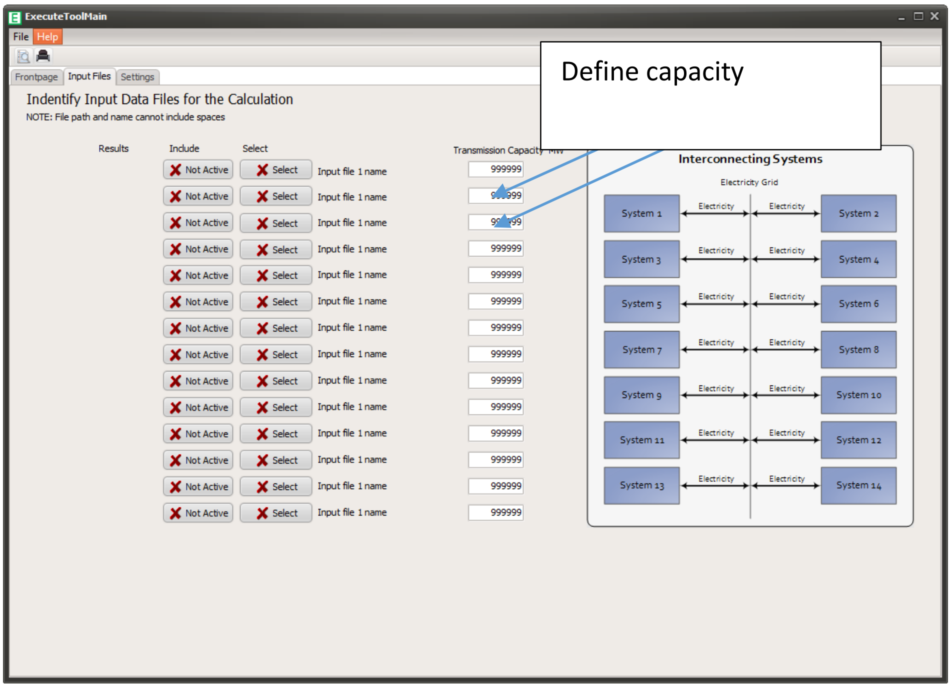
<tr>
<td>Define transmission capacity from each system going into the grid.</td>
<td>
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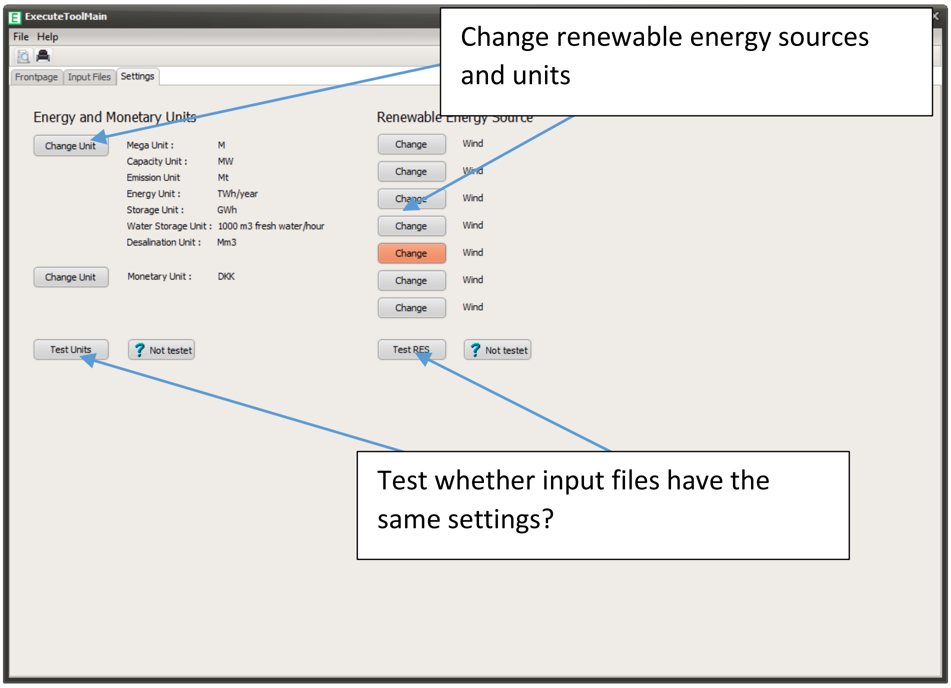
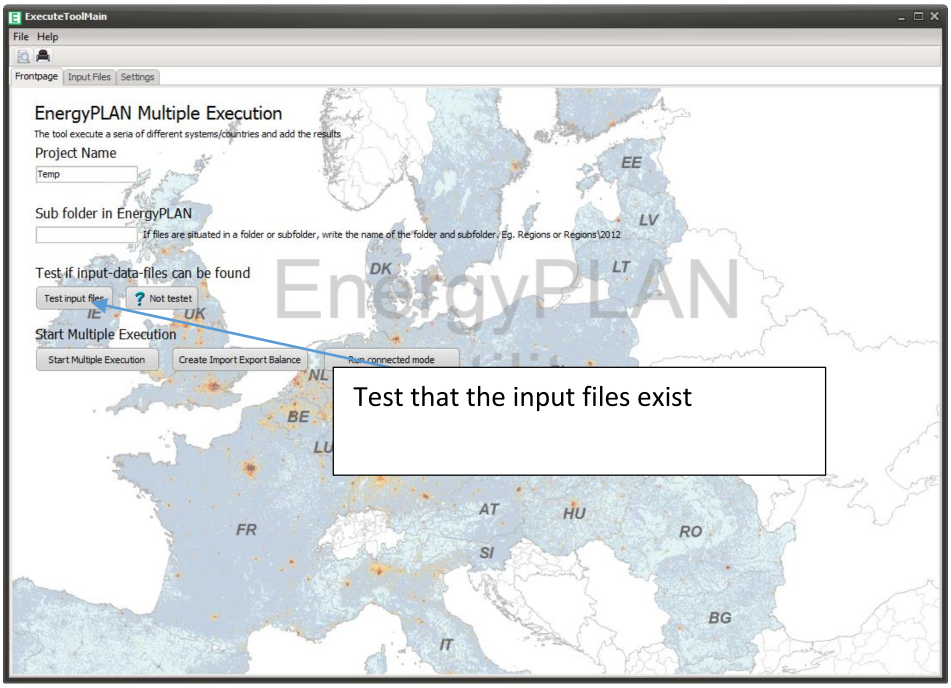
Go to settings to define the size of the system, the currency, and renewable energy technologies. For each setting there is a button that confirms whether the input files are set correct. These settings are not needed to run the model, but will help the user generate the right print out heet.

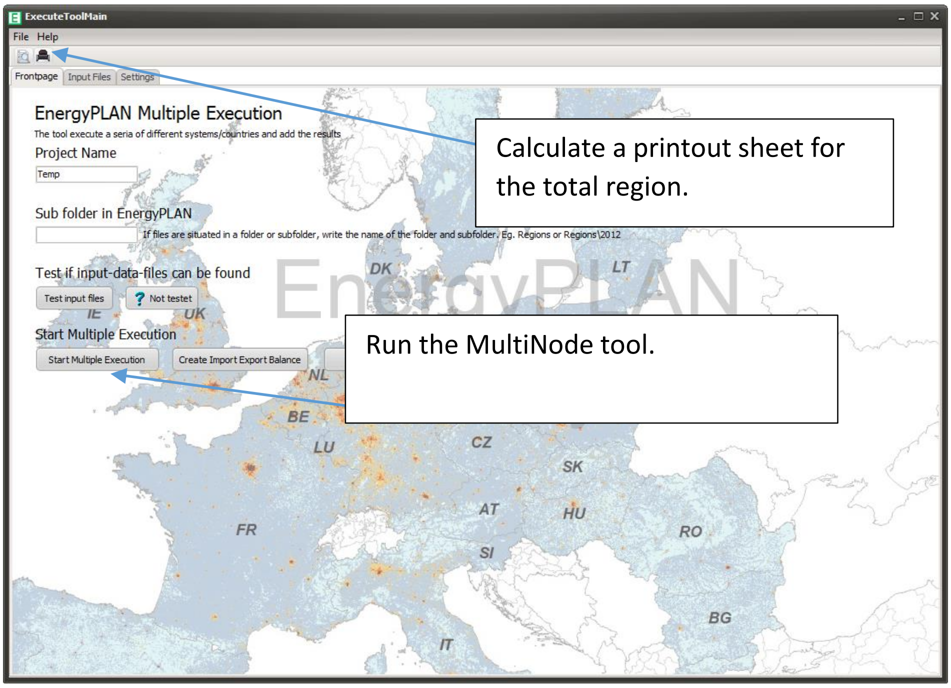


To run the tool the first step is to test that all the input files exist on the front page.

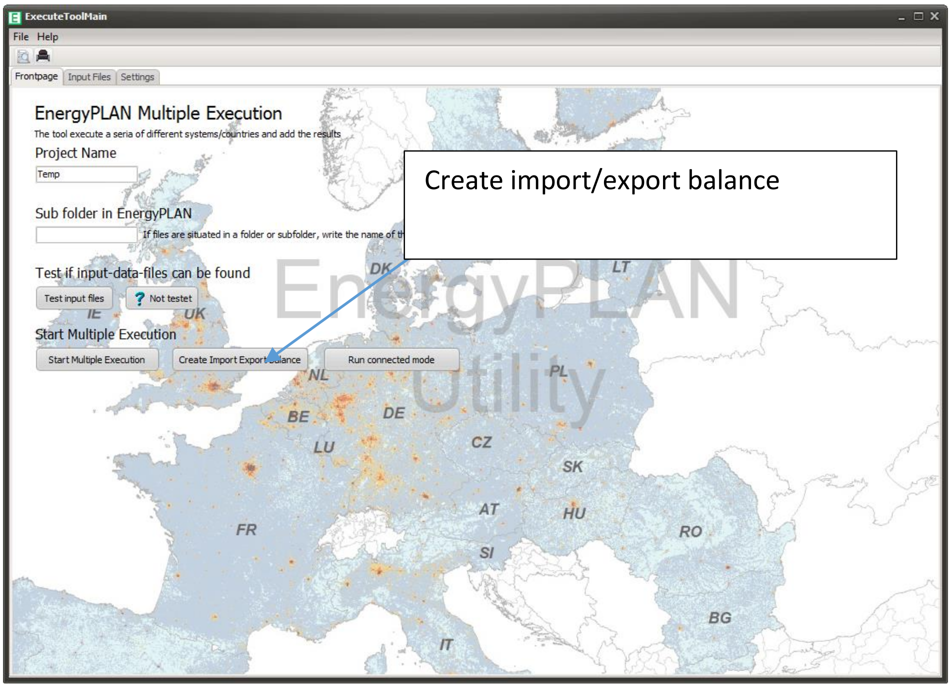


The next step is to press the start Multiple Execution. This will run each EnergyPLAN model as an island mode, and store the results.

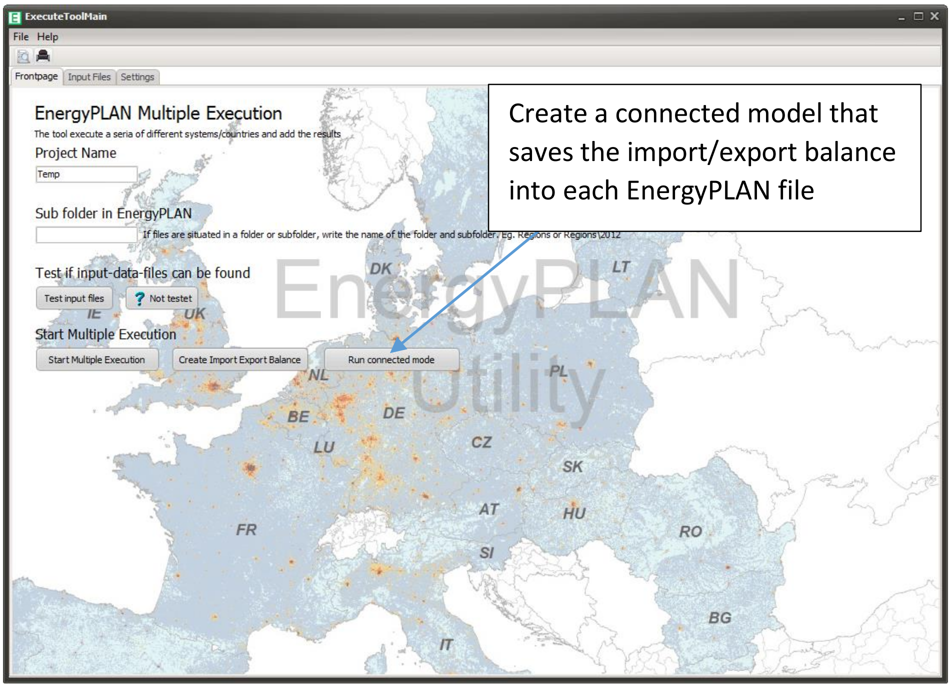
Hereafter, you can create a printout to see how the system operates without interconnection between them.



After that, pressing the create import/export balance will analyse each system, and define how much should be imported and exported to each system.



Finally, the “Run connected models” button will save all your systems with the import/export balance. You can load these into the MultiNode tool under input files and run the tool again, to see how the overall system performs with connection.



Calculating connections using MultiNode

The MultiNode tool operates based on four different buttons. These operations are described in detail in the following subsections.

Start Multiple Calculation

When pressing start multiple calculation MultiNode runs each defined system as an island mode operation. It stores all information from the EnergyPLAN operation in the memory in a number of files. One file that summarizes all the selected systems and separate files for each individual system. The stored data also includes temporarily information necessary to calculate average efficiencies when running the print out button.

Create Import/Export Balance

Abbreviations:

P = Potential

PP = Power plant

Prod = production of electricity

Imp = Import

Ini = initial

N = Number of systems

1..14 = The specific system

Based on the stored output data from each individual system the tool creates an import/export balance, following the basic structure illustrated in Figure 1.

The first step of creating the import/export balance is to calculate the total amount of export available on the grid each hour. This is done by identifying the amount of exportable electricity each system delivers and add them all together for each hour:

$$export_{total} = export_1 + export_2 + export_3 \ldots + export_{14}$$

Each of the individual exports can maximum equal the defined capacity on the interconnector.

After this, the amount of potential imports are identified for each system by adding together the important demand the current operation of the power plant. This is done for every hour in the year.

$$\begin{aligned} P_{imp1} &= import_{demand1} + PP_{prod1} \\ P_{imp2} &= import_{demand2} + PP_{prod2} \\ &\vdots \end{aligned}$$

$$P_{imp14} = import_{demand14} + PP_{prod14}$$

Each individual import demand can only be as high as the capacity on each transmission line.

For each system the program creates an initial hour balance that defines the export as positive and the potential import as negative for each system:

$$\begin{aligned}
&Balance_{ini1} = export_1 - P_{imp1} \\
&Balance_{ini2} = export_2 - P_{imp2} \\
&\vdots \\
&Balance_{ini14} = export_{14} - P_{imp14}
\end{aligned}$$

However, the system can only import if there is available electricity in the grid. This means that based on the merit order in which the systems are organized in the program they will each take turn in taking electricity out of the grid as import. Therefore it will check whether there is electricity in the grid for each hour with a potential import demand. If that is the case an import demand will be defined:

$$\boldsymbol{if}\left(P_{imp1} > export\ total\right)\ \boldsymbol{then}\ Import_1 = exportable_{total}\ \boldsymbol{else}\ Import_1 = P_{imp1}$$

$$\begin{aligned}
&\boldsymbol{if}\left(P_{imp2} > export\ total - import_1\right)\ \boldsymbol{then}\ Import_2 = exportable_{total} - import_1\ \boldsymbol{else}\ Import_2 \\
&\qquad = P_{imp2} \\
&\vdots \\
&\boldsymbol{if}\left(P_{imp14} > export\ total - import_1 \ldots - import_{13}\right)\ \boldsymbol{then}\ Import_{14} \\
&\qquad = exportable_{total} - import_1 \ldots - import_{13}\ \boldsymbol{else}\ Import_{14} = P_{imp14}
\end{aligned}$$

These sections secure that only potential import that can be covered by the grid is included.

Therefore, the balance can now be created. This is done by taking the initial balance and replace the export, with the sum of imports needed in the other system, while the potential import is replaced with the actual import found in the previous section. This is done for every hour:

$$\boldsymbol{if}(Balance_{ini1} > 0)\ \boldsymbol{then}\ Balance_1 = import_2 + import_3 \ldots + import_{14}\ \boldsymbol{else}\ Balance_1 = -import_1$$

$$\begin{aligned}
&\boldsymbol{if}(Balance_{ini2} > 0)\ \boldsymbol{then}\ Balance_2 = import_1 \ldots + import_3 \ldots + import_{14}\ \boldsymbol{else}\ Balance_2 \\
&\qquad = -import_2 \\
&\vdots \\
&\boldsymbol{if}(Balance_{ini14} > 0)\ \boldsymbol{then}\ Balance_{14} = import_1 + import_3 \ldots + import_{13}\ \boldsymbol{else}\ Balance_{14} \\
&\qquad = -import_{14}
\end{aligned}$$

The result is a balance file for each system, where the export is positive and the import is negative.

The consequence of this method is that the export part is not in balance with the import part. Therefore, the final step is to remove the excess accounted electricity by diving the active export in each system in each hour with the number of systems that exports electricity. Thus eliminating excess exports. The following concept is used for each balance:

$$\begin{aligned}
&\boldsymbol{if}\,(Balance_1 < 0)\ \boldsymbol{then}\ \ Balance_1 = Balance_1 \\
&\boldsymbol{else\ if}\ Balance_1 + Balance_2 \dots + Balance_{14} = 0 \\
&\boldsymbol{then}\ Balance_1 = Balance_1\ \boldsymbol{else} \\
&Balance_1 = \frac{Balance_1}{N_{active}}
\end{aligned}$$

The balances can be seen by pressing the view screen button and can be found in the EnergyPLAN distribution files folder.

Run Connected Mode

The run connected mode button uses the information from the created import/export balance and the loaded input files to create new EnergyPLAN scenario files. These are the original files but uses the fixed import/export input in EnergyPLAN to include the import/export balance created.

The import/export balance is included as a distribution file and a sum to indicate the total annual demand. A negative demand indicates an annual import of electricity while a positive demand indicate an annual export of electricity.

Printout

Abbreviations:

P = Potential

Cap = Capacity

Eff = Efficiency

PP = Power plant

El = production of electricity

Fuel = Fuel consumption

1..14 = The specific system

The final button in the MultiNode is the print out. This is used to summarize all the EnergyPLAN outputs into one single combined output. This is useful, when using the MultiNode tool to simulate systems split into several systems. This could be a country split into counties or regions, or parts of Europe modelled as each individual country. Then the printout button can make final output sheet for the country or for Europe.

Compared to the printout in EnergyPLAN, the MultiNode print out is simplified. This means it only includes information that can be either added together or defined through weighted averages.

This means that all costs, capacities and demands are added together based on. For instance for electricity demand and power plant capacity:

$$Elec\ demand_{total} = Elec\ demand_1 + Elec\ demand_2 \dots + Elec\ demand_{14}$$

$$PPcap_{total} = PPcap_1 + PPcap_2 \dots + PPcap_{14}$$

The average efficiencies for all fuel consuming fuel plants are calculated based on the total energy output divided with the total fuel consumption. For instance for power plants:

$$PP_{eff} = \frac{El_{PP}}{Fuel_{pp}}$$

For efficiencies for non fuel using plants, the efficiency is calculated based on calculating capacities before and after efficiency loss for each system. These are both summarized and based on this an average capacity is found. For instance for hydro power:

$$Hydro_{eff} = \frac{Cap_{after\ loss}}{Cap_{before\ loss}}$$