HOW TO GUIDE

The MILP Solver optimization method in energyPRO

energyPRO

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About energyPRO

energyPRO is a Windows-based modeling software package for combined techno-economic analysis and optimisation of complex energy projects with a combined supply of electricity and thermal energy from multiple different energy producing units.

The unique programming in energyPRO optimises the operations of the plant including energy storage (heat, fuel, cold and electrical storages) against technical and financial parameters to provide a detailed specification for the provision of the defined energy demands, including heating, cooling and electricity use.

energyPRO also provides the user with a detailed financial plan in a standard format approved by international banks and funding institutions. The software enables the user to calculate and produce a report of the emissions by the proposed project.

energyPRO is very user-friendly and is the most advanced and flexible software package for making a combined technical and economic analysis of multi-dimensional energy projects.

For further information concerning the applications of energyPRO please visit www.emd.dk.

Terms of application

EMD International A/S, June 2020

Contents

In this How To Guide you will learn how to use MILP Solver as a calculation method in energyPRO.

Click the bullets below to jump to the relevant chapter.

Introduction

Flexible energy plants providing electricity, heating and cooling represent an important part of future smart energy systems based on renewable energy. Equipped with large combined heat and power units, heat pumps, electric and absorption chillers and energy storages, like thermal storages, chilled water storages and batteries, these have the possibility to provide flexibility – but an optimized dispatch of the production units is required.

energyPRO offers two dispatch methods – an advanced analytic method and a Mixed Integer Linear Programming (MILP) method.

In literature it is made probable that no single dispatch method will be able to solve all dispatch problems, therefore, an option is to make use of and combine the best of e.g. analytic and solver-based dispatch methods. This combination will even improve the dialogue with operators of DE plants, who have extensive experience in the complexity, non-linearities and constraints of the daily operation of the energy plants. We have detailed this challenge in the reviewed paper, Analytic versus solver-based calculated daily operations of district energy plants [1].

In this How To Guide the MILP method is described. We have in the guide shown complicated examples where the MILP performs well, e.g.:

- Trigeneration plant with both hot water and chilled water storages
- Carbon Capture and Utilization plants
- Hybrid windfarm, PV and battery plants with restricted access to the electrical grid

What is a MILP Solver

Mixed Integer Linear Programming Solver finds solutions to problems specified as:

$$\min c^T x$$

$$A \cdot x \leq b$$

$$Aeq \cdot x = beq$$

$$lb \leq x \leq ub$$

$$x_i \in \mathbb{Z} \ \forall i \in \mathrm{I}$$

Where:

- x – vector of variables
- c^T – vector of coefficients of the objective function
- A – matrix of variables’ coefficients in the inequality constraints
- b – vector of constants used in the inequality constraints
- Aeq – matrix of variables’ coefficients in the equality constraints

- beq – vector of constants used in the equality constraints
- lb – vector of lower bounds of variables
- ub – vector of upper bounds of variables
- x_i – integer variables

In other worlds, MILP Solver finds the solution to a problem defined with linear constraints and objective function, where some of the variables can be binary or integer. The ability to describe an energy system with a set of linear constraints enables to use a MILP Solver as a calculation method in energyPRO.

Advantages of the MILP Solver method

The main advantage of a MILP Solver method is the accuracy of solution. If the problem is defined well the solution found with use of MILP Solver is the optimal solution of the problem.

The other advantage is that the optimal dispatch is found without the need to adjust the operating strategy of the units.

The default solver – CBC

CBC is an open-source mixed integer programming solver written in C++. It is released as open source code under the Eclipse Public License (EPL) and is freely redistributable. Cbc is distributed by the COIN-OR initiative. The Cbc website is https://github.com/coin-or/Cbc.

According to the studies performed in [2] and [3] CBC is the fastest available open-source solver.

Setting up a calculation with MILP Solver

The user can decide on the method used for the calculation – Analytic or MILP Solver. This chapter presents how to set up a calculation with MILP Solver.

Choosing MILP Solver as method for calculation

The calculation method can be chosen in Project identification or Operation strategy window.

The easiest approach is to use the *Calculation method* button (Figure 1), which directly opens the *Calculation method* tab in *Project identification*, which is presented in Figure 2. To perform the calculation with MILP solver, *MILP* must be chosen in *Type of Solver* field.

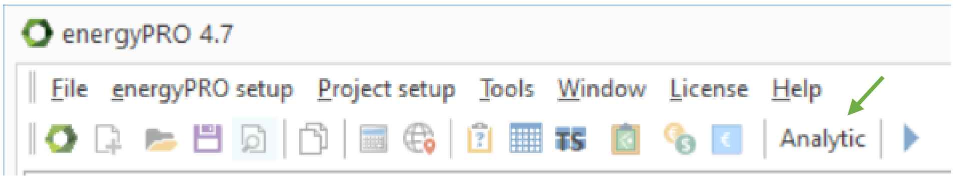

Figure 1: Calculation method button

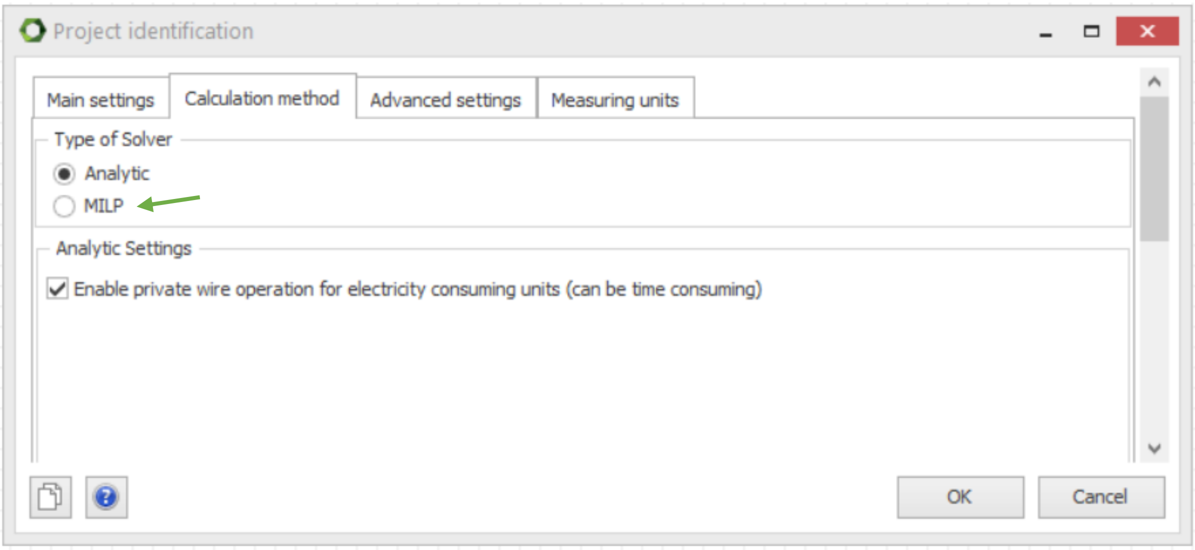

Figure 2: Calculation method tab in Project identification window

As mentioned before, the calculation method can also be changed in the *Operation strategy* window. The *Calculation Method* section is shown in the window and the choice can be made also there – Figure 3.

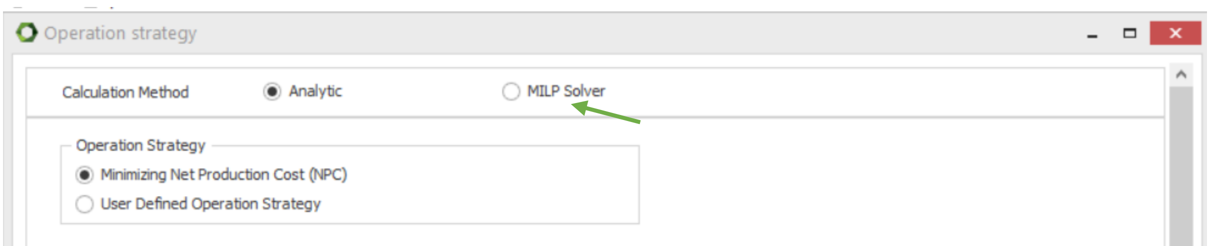

Figure 3: Calculation Method section in Operation strategy window

Setting parameters of MILP Solver

It is possible to change two parameters of the calculation with use of the MILP Solver in energyPRO. This can be done in *Calculation method* tab in *Project identification* window – presented in Figure 4. The two parameters are *Max. solution time* and *Wanted precision*.

Max. solution time – indicates the maximum time of one calculation. One calculation is considered to cover the length of optimization period. If the length is chosen to be Month and the project is calculated for a year, 12 calculations are going to be performed. The Max. solution time will not affect quick calculations but will stop the optimization if it did not reach a solution with wanted precision within the specified time. The default value is 120 seconds.

Wanted precision – indicates the precision of calculation which must be reached to stop it. The precision may be interpreted as an indicator of how far the solution is from the optimal one. It is a very important parameter and may highly influence the time it takes to obtain the result. If the precision is set to be a very small number, the calculation may take a long time. It is because the calculation will not be stopped until the Wanted precision is reached or the Max. solution time exceeded. The default value of Wanted precision is 1%.

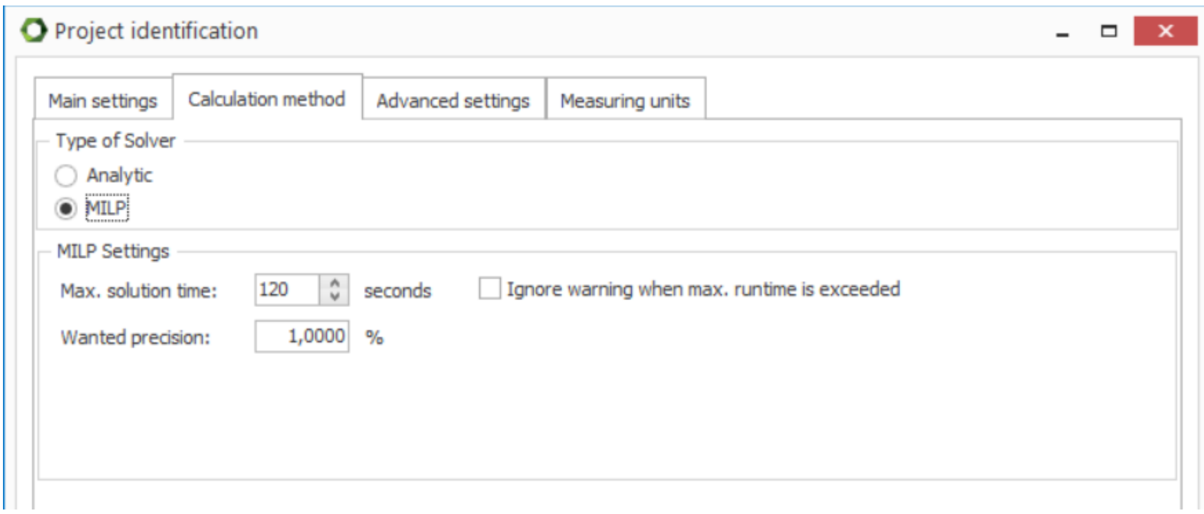

Figure 4: MILP Settings with default values, the presented parameter are the default values for calculation

Usually, a feasible solution of the problem is obtained in the first iterations of simulation. Most of the times this solution is far from the optimal, but it satisfies all constraints of the system. The MILP Solver attempts to improve the feasible solution in the next iterations.

Warning and possible solution

If the Max. solution time is reached and wanted precision is not met, a warning is displayed (as in Figure 5). It indicates all the calculations for which the time limit was reached and the Precision of the calculation. The solution displayed in energyPRO, after the warning, is the best feasible solution achieved within the time limit. To reach the wanted precision the user should consider increasing the Max. solution time. To speed up the calculation it is advised to decrease the wanted precision (enter a larger percentage).

The warning may be disabled in MILP Settings by selecting the checkbox *Ignore warning when max. runtime is exceeded.*

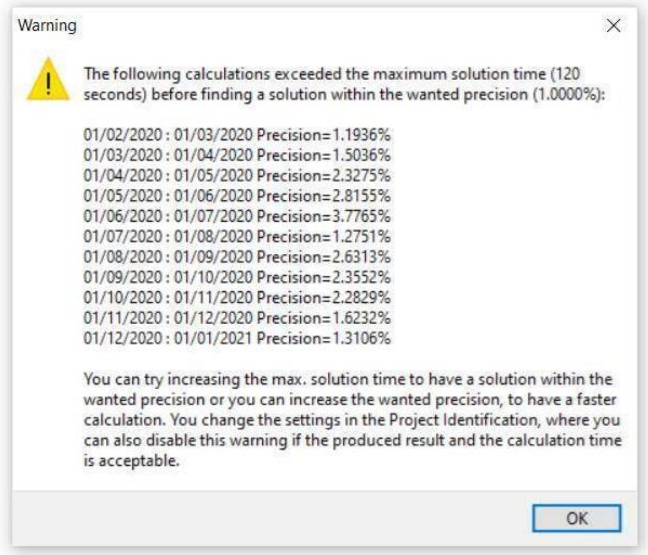

Figure 5: Warning displayed when Max. solution time is exceeded

Using other solvers than the default CBC

The default MILP Solver, included in energyPRO installation, is CBC. It is an open-source MILP solver, which proved to have the best performance out of the available open-source MILP Solvers. Nevertheless, in highly complicated simulations the commercial MILP Solvers prove to be more efficient. Therefore, a possibility to use one of the commercially available Solvers is included in energyPRO. The compatible Solver is Gurobi.

The solver can be changed in Options in energyPRO setup menu as presented in Figure 6. The change is not project specific but is introduced in all the projects.

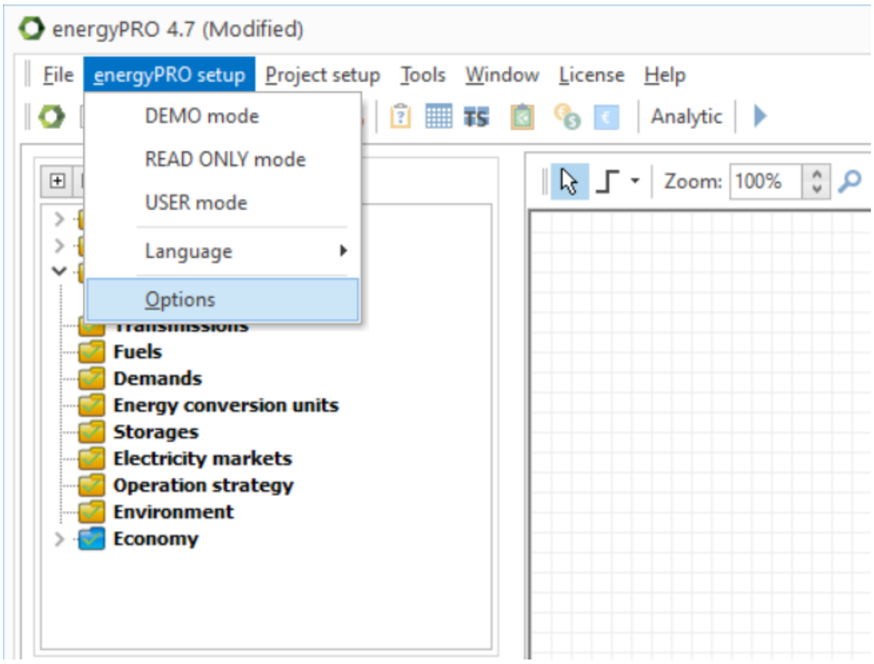

Figure 6: Options in energyPRO setup

In *Options* the *MILP Solver* tab should be selected. To change the MILP Solver *Gurobi* must be chosen as presented in Figure 7. The field *Path to solver executable* should include the path to gurobi_cl.exe file on the user's computer. If the installation of Gurobi was done with default settings the path should be similar to the one in Figure 7. However, it may vary between versions.

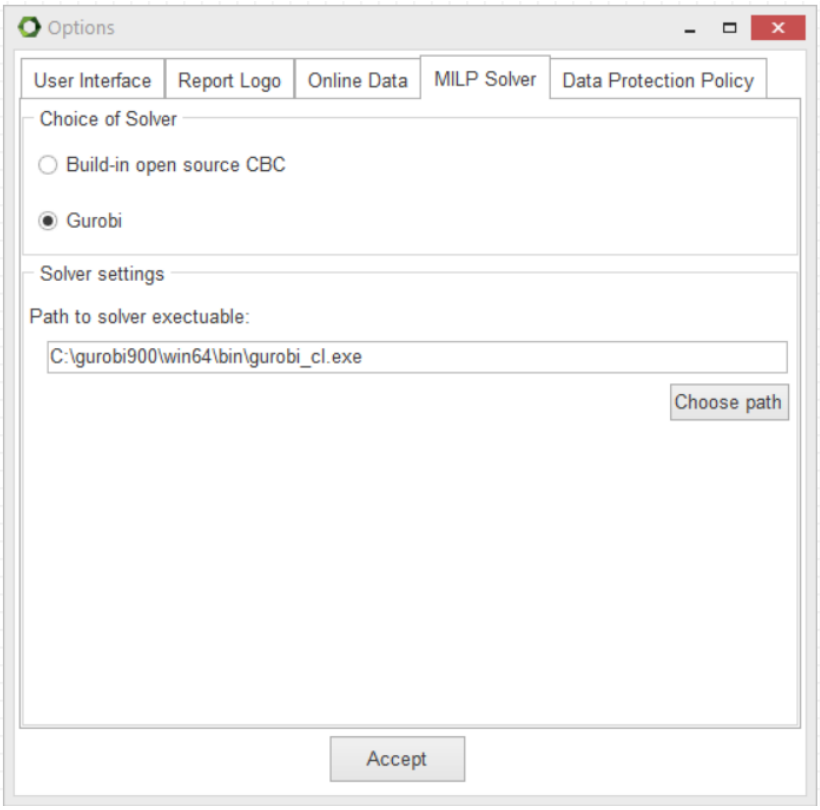

Figure 7: Choice of Solver in Options

Limitations of the MILP solver

This chapter presents the functions, which are not implemented in the calculation with MILP Solver or are implemented with limitations.

1. Modelling of "Production to store not allowed"

The current implementation of the constraint has a limitation. If the unit is not allowed to produce to store but is allowed to transmit to other sites, the solution generated by solver will not prevent that the transmitted energy to the other sites is stored in these sites.

2. German Functions not yet implemented

The German Functions are not implemented in the current release.

3. Non-linear objective functions

A payment expressed with non-linear equation cannot be used when MILP Solver is used as a calculation method. Non-linear terms are all the terms where two or more variables are multiplied. Obviously, the variables can be multiplied by constants such as coefficients or prices.

4. Limited implementation of max(), min() and if() functions

The implementation of the max(), min() and if() functions is very limited when MILP Solver is chosen as the calculation method. In the current approach it is done by stepwise assuming that 1 MWh of a certain energy type is produced or consumed by a certain production unit, when all others are zero. An example with max() function implementation is:

The payment: $max(EC(HP) - EP(BiogasCHP); 0) \cdot SpotPrice(\_)$

This payment will thus to the electricity produced by $BiogasCHP$ in a certain time step add to the objective function:

$$\max(EC(HP) - EP(BiogasCHP); 0) \cdot SpotPrice(\_) = \max(0 - 1; 0) \cdot SpotPrice(\_) = 0$$

This payment will thus to the electricity consumed by HP in a certain time step add to the objective function:

$$\begin{aligned}\max(EC(HP) - EP(BiogasCHP); 0) \cdot SpotPrice(\_) &= \max(1 - 0; 0) \cdot SpotPrice(\_) \\ &= SpotPrice(\_)\end{aligned}$$

This implementation can create inaccurate objective functions. Therefore, it is advised to avoid using these functions in the payments when MILP Solver is chosen as the calculation method.

Work arounds

As described in "Limitations of the MILP solver" there are in the solver in this energyPRO release still a need for work arounds.

An example of such a work around is presented in this section.

An ECU not allowed to store is only prohibited to use storages in the same site. If the storage is located in another site, the unit will be able to use it.

This undesired behavior can be observed in the project presented in Figure 8. The Boiler in the project can produce 4 MW and is not allowed to part load, the Heat Demand is constant – 3MW. Therefore, it is only possible to satisfy the demand if the storage is used. However, the Boiler is prohibited from producing to store. If the ECU and Thermal Store are in separate sites, the Boiler still uses the Thermal Store in Site 2 as shown in Figure 9.

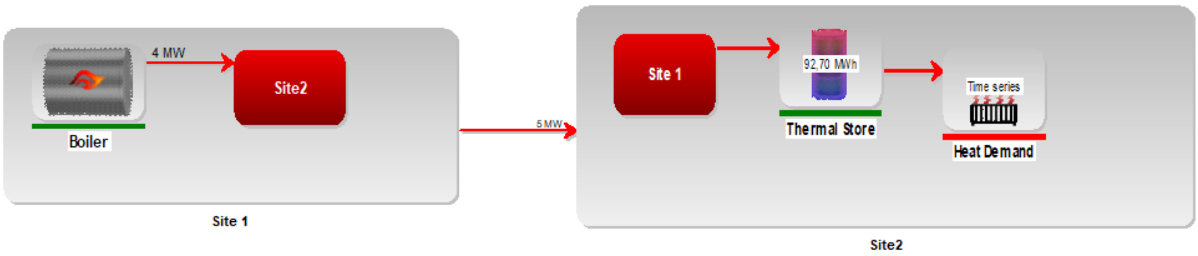

Figure 8: Project with storage and ECU in separate sites

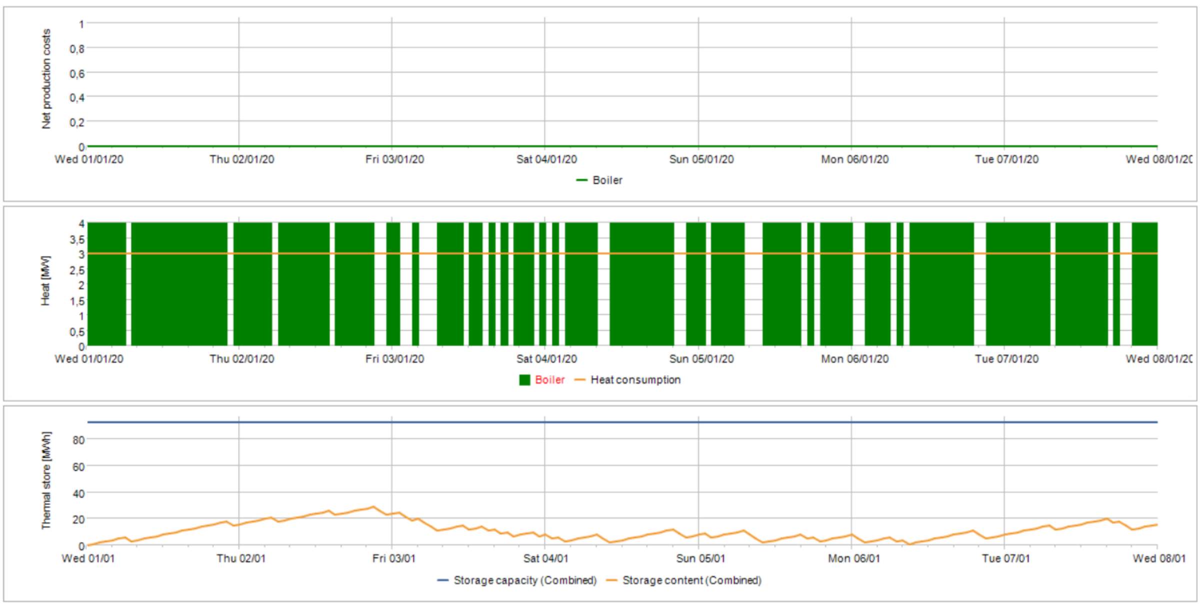

Figure 9: Storage in Site 2 used even though Boiler in Site 1 is prohibited from producing to store

A work around for this type of situation is to move the storage to the same site as the ECU prohibited from producing to store. When this is done, the storage is no longer used. In the example with two sites, the demand is not met because the storage cannot be used by the boiler. The dispatch is shown in Figure 10.

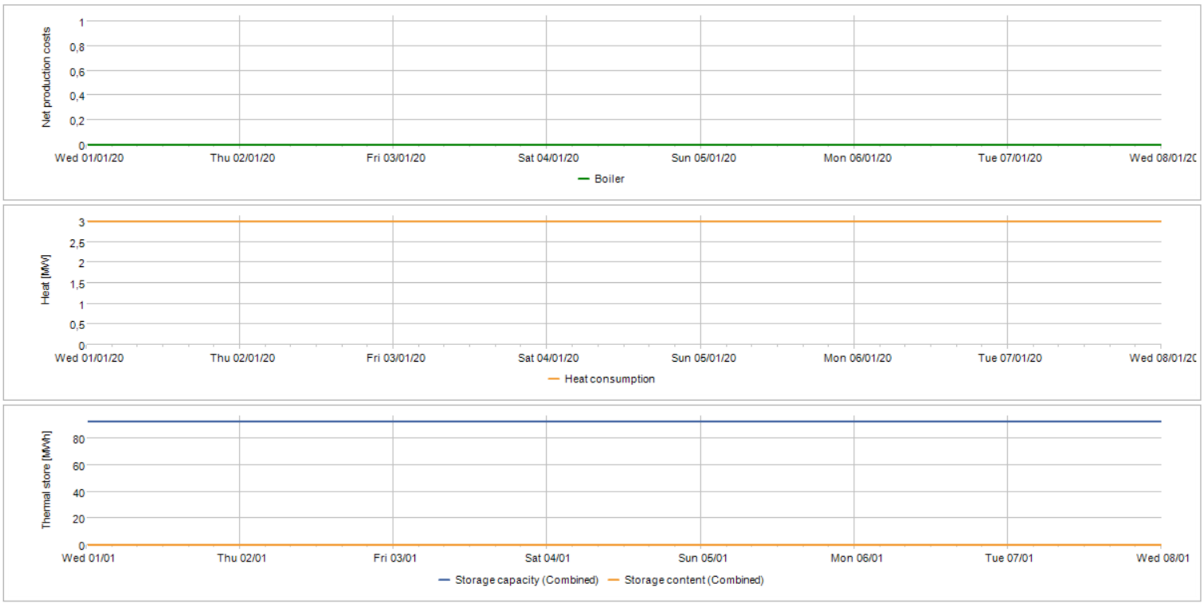

Figure 10: Storage in Site 1 is not used and the demand is not met

Examples of the method

Production of synthetic fuels

One of the applications of the MILP Solver is to perform calculation of synthetic fuels production. The example presented in Figure 11 focuses on production of methanol.

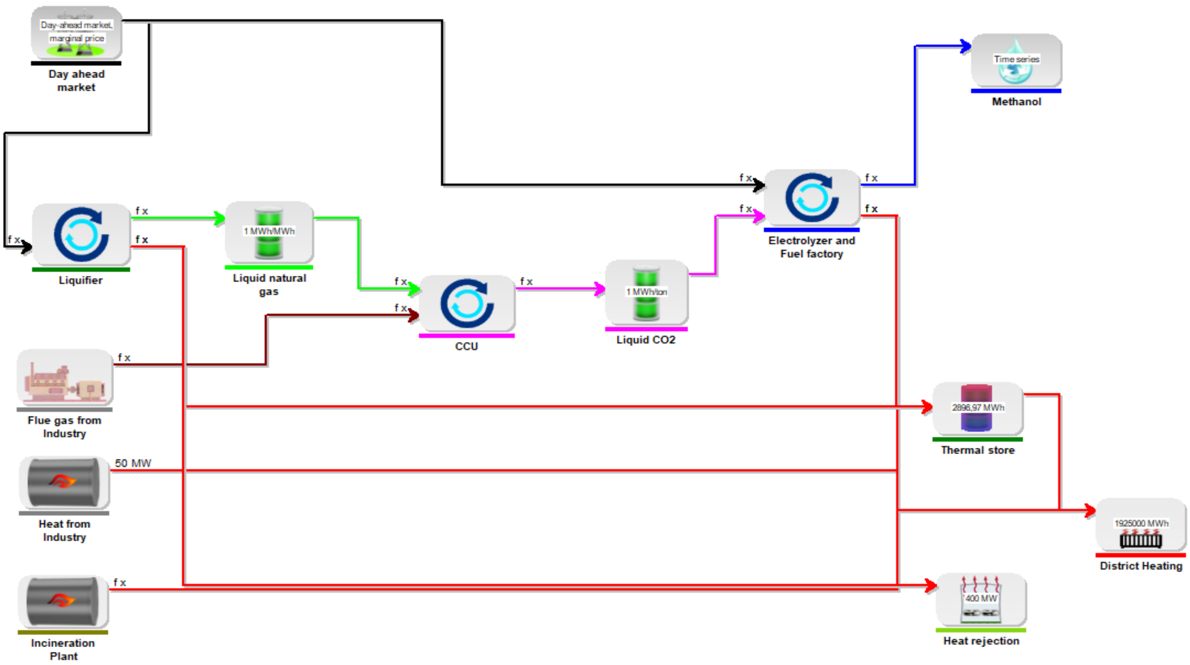

Figure 11: energyPRO example of synthetic fuels production

The dispatch of the units for one-week is presented in Figure 12.

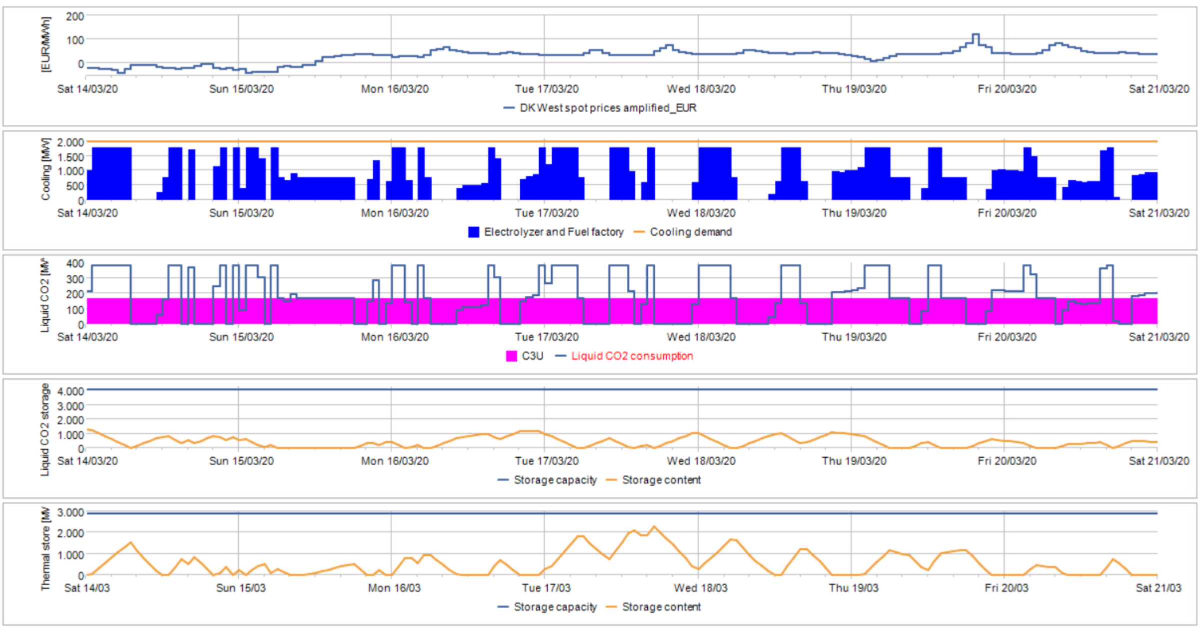

Figure 12: Dispatch of the units and operation income calculated with MILP Solver in example of synthetic fuels production

Trigeneration plant with hot water and chilled water storages

The MILP Solver calculation method performs very well when ECUs depending on production from other ECUs are used. In the trigeneration example, presented in Figure 13, the chilled water production is dependent on the output of heat and electricity producing units.

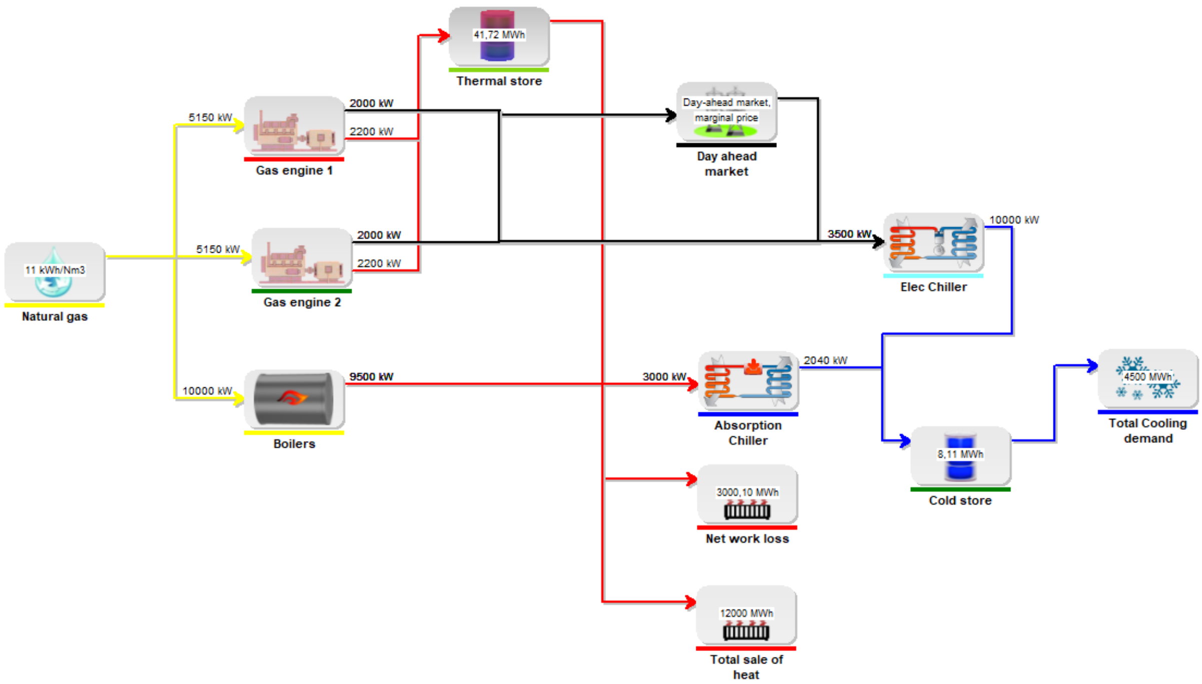

Figure 13: energyPRO example of trigeneration plant

Figure 14: Dispatch of the units and operation income calculated with MILP Solver in example of trigeneration

The dispatch of the units and operation income calculated with MILP Solver is presented in Figure 14. The dispatch and income calculated with Analytic method is shown in Figure 15. The income calculated with MILP is significantly higher, what proves the advantage of MILP over Analytic method when ECUs depending on production from other ECUs are used in the project. For one-month calculation is August the income is increased by around 6000 EUR when MILP is used.

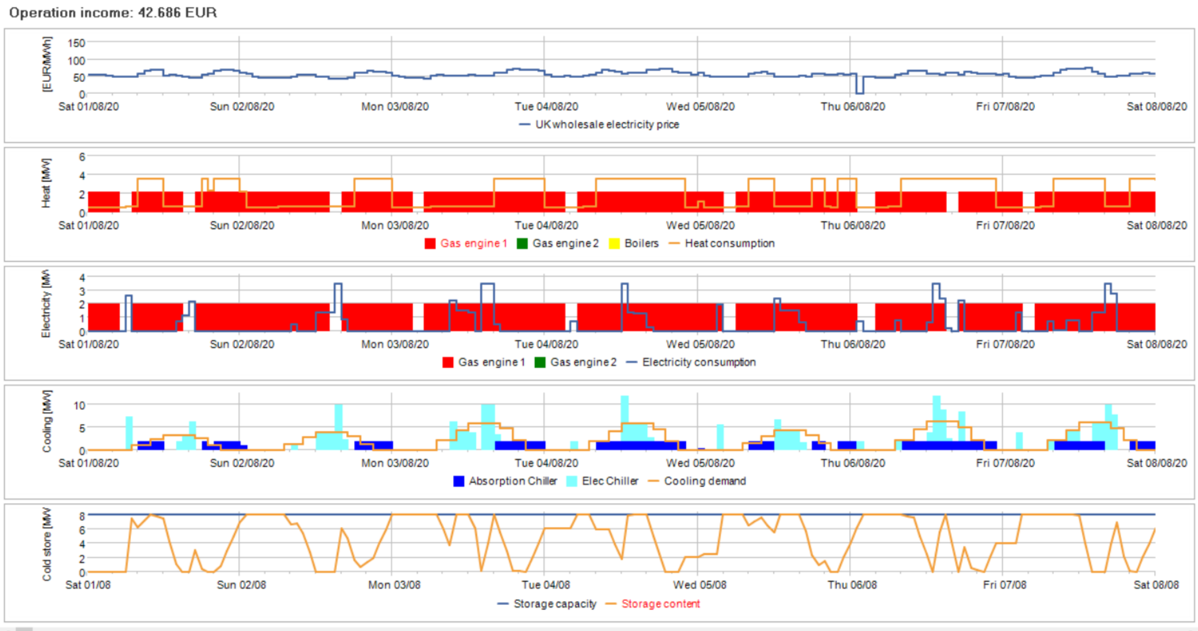

Figure 15: Dispatch of the units and operation income calculated with Analytic method in example of trigeneration

PV and WTG and battery participating in day-ahead market with market restrictions

Another representative example of MILP Solver in energyPRO is shown in Figure 16. It is a simple example of renewable energy sources and battery connected to the grid. The advantage of using a MILP Solver is that market restrictions can be introduced as shown in Figure 17. The combined maximal capacity of the Wind farm and Solar photovoltaic is 70.05 MW, whereas the Max Export Capacity is set to be 50 MW. Import of electricity to charge the battery is prohibited by setting the Max Import Capacity to 0 MW.

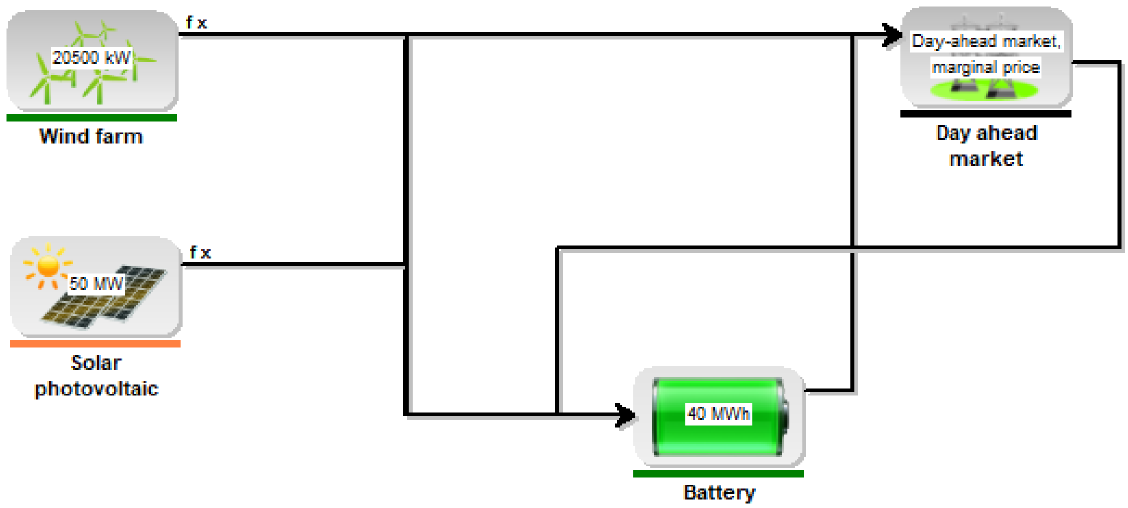

Figure 16: energyPRO example of project with market restrictions

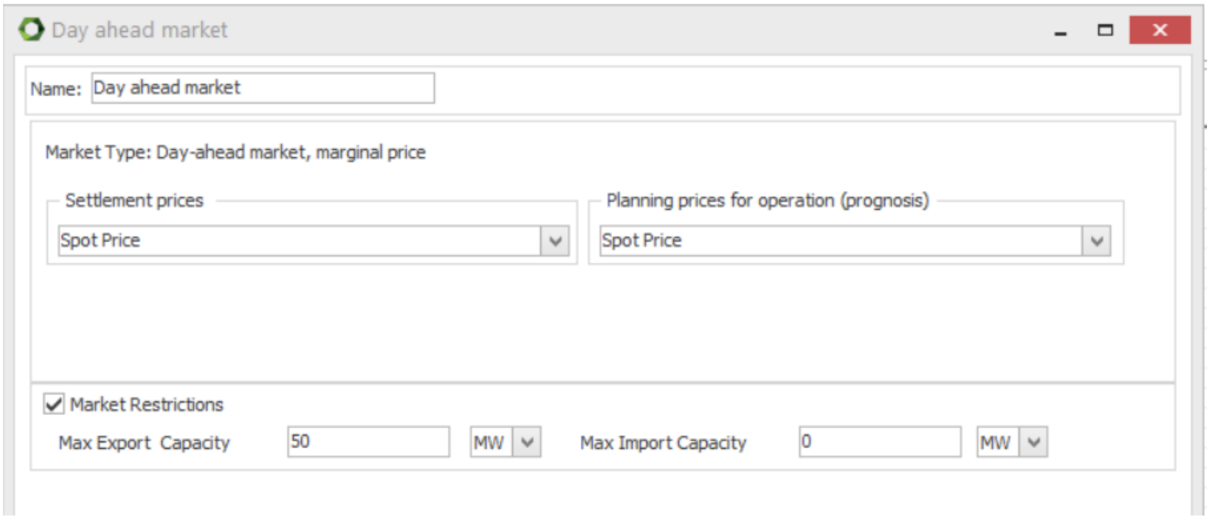

Figure 17: Market restrictions in energyPRO example

The dispatch of the units throughout a week of operation is presented in Figure 18.

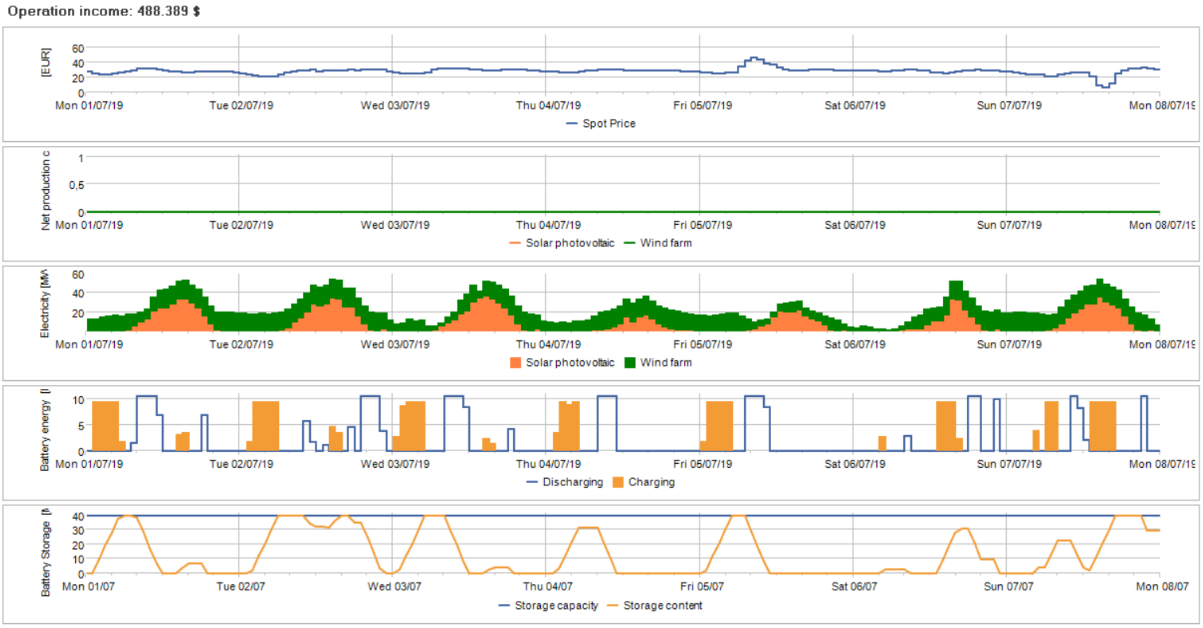

Figure 18: Dispatch of the units and operation income calculated with MILP Solver in example with market restrictions

Reference list

[1] A. N. Andersen and P. A. Østergaard, “Analytic versus solver-based calculated daily operations of district energy plants,” *Energy*, vol. 175, pp. 333–344, 2019, doi: https://doi.org/10.1016/j.energy.2019.03.096.

[2] B. Meindl and M. Templ, “Analysis of commercial and free and open source solvers for linear optimization problems,” *ESSnet commom tools Harmon. Methodol. SDC ESS*, vol. 1, no. 1, pp. 1–14, 2012, [Online]. Available: http://www.statistik.tuwien.ac.at/forschung/CS/CS-2012-1complete.pdf.

[3] J. L. Gearhart, K. L. Adair, J. D. Durfee, K. A. Jones, N. Martin, and R. J. Detry, “Comparison of open-source linear programming solvers.,” doi: 10.2172/1104761.

Please notice, that you can find more information on how to use energyPRO in the How to Guides, User's Guide and tutorials on EMD's website: http://www.emd.dk/energypro/