Optimizing the design and operation of 5GDHC networks

A final report on the COOLGEOHEAT project

Report written by Filippa Sandgren, Utilifeed AB

September 2022

This project is done with financial support from InterregÖKS and the EU Regional Development fund

Table of Contents

Introduction

When operating and designing district heating and cooling grids it is important to do it as efficiently as possible, from a system perspective. This can be fairly straightforward in traditional district heating systems, but the energy system is becoming more complex and dynamic with high variations in electricity prices. At the same time flexibility is introduced, which adds great value but at the same time increases the complexity further. For these reasons, new tools are needed that can handle the complexity and optimize both the design and operation of 5GDHC networks and modern interconnected energy systems.

Optimization & Scenario Analysis

Utilifeed has previously developed an Optimization software that optimizes the district heating and cooling production for the upcoming days. The heating and cooling demand are forecasted with Utilifeed's machine learning algorithm EnergyPredict. The production is then optimized each hour, to minimize the total operational cost for the whole time period.

When looking at the design of district heating and cooling systems, new or existing, it is essential to look at longer time periods, typically years, to get an idea of how the system is performing. Therefore Utilifeed has, within this project, further developed the Optimization software to also fulfill this purpose. The model has been developed to handle longer time periods and larger changes in the system. This feature is called Scenario Analysis.

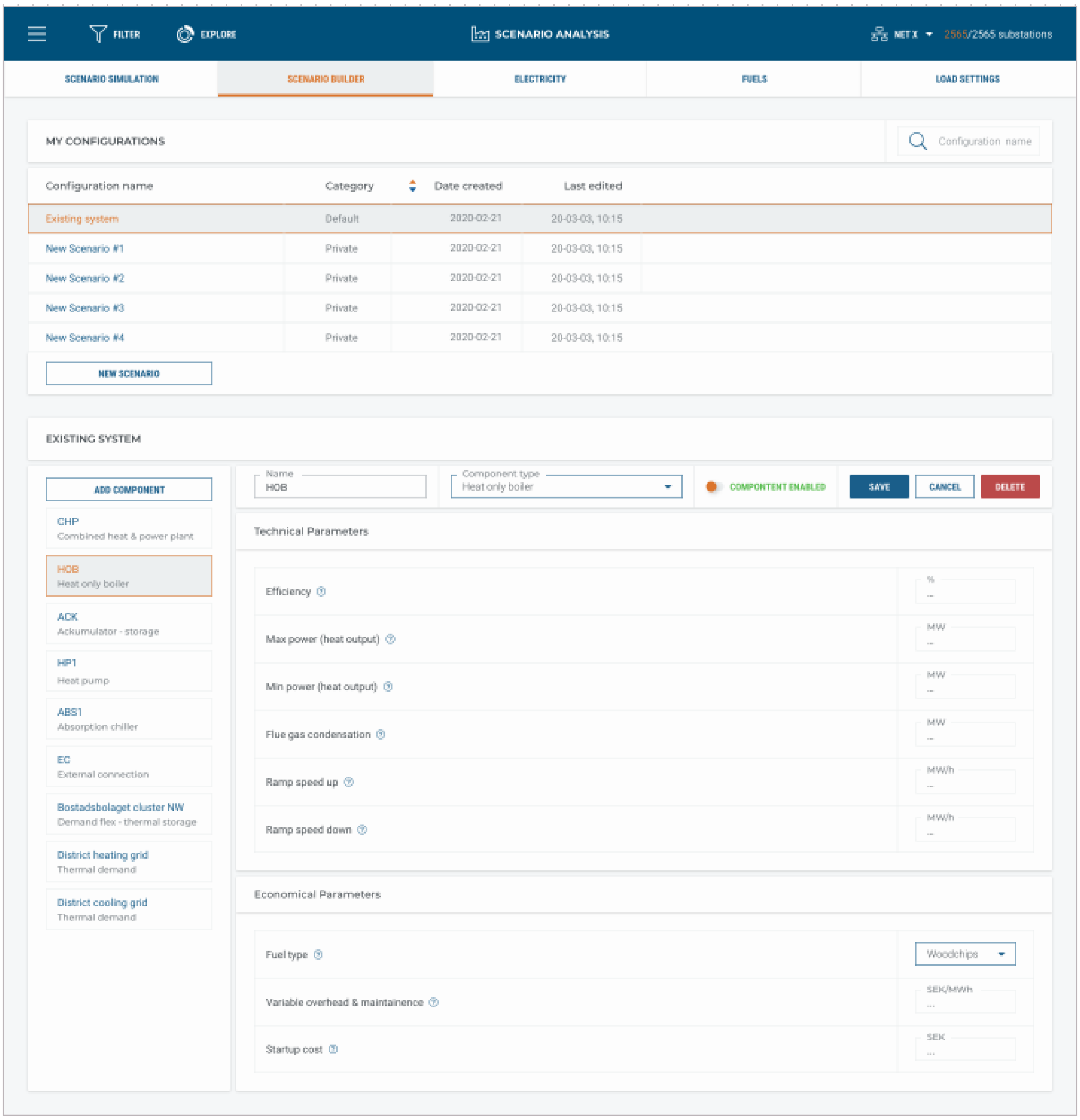
In Scenario Analysis it is possible to simulate different scenarios, for the same time period, to be able to compare operational costs. First, the reference scenario is simulated. If there is an existing system, the setup for that is used. Inputs are historical demand, existing production units, and historical fuel and electricity prices. The operation of this reference system is then optimized, to minimize the operational costs for the whole year.

Several different scenarios can then be created. Those scenarios can look completely different from the reference case, or be pretty similar. For a small 5GDHC network, it might be interesting to compare the operational cost if the system has a large number of small heat pumps, with the operational cost if the system has one common wood chip boiler. In this case, the two systems look fairly different. On the other hand, it can also be interesting to investigate how affected the system is by changing electricity prices. Then the different scenarios can just have different electricity prices.

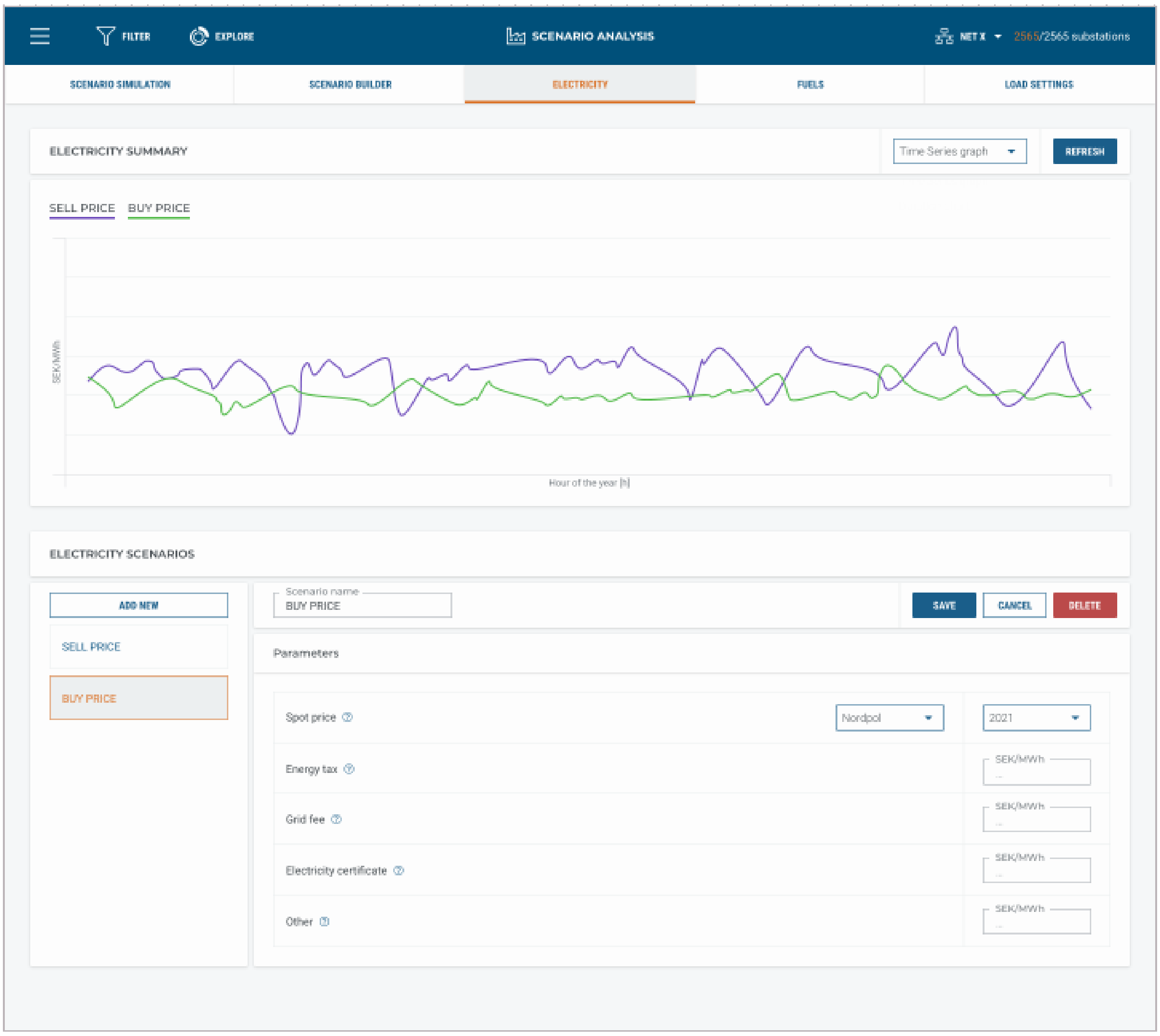
Different types of flexibility are included in the Optimization software, and all of them have been adapted to also work with Scenario Analysis. The models can handle storage tanks, both for heating and cooling, simple boreholes, and demand-side flexibility. There are two different types of demand-side flexibility: shift between demand-side heat pumps and district heating, and Building Inertia Thermal Energy Storage (BITES). BITES is especially interesting to investigate together with small-scale heat pumps since this can decrease the installed capacity significantly. BITES also enables the operation of heat pumps to be optimized against a variable electricity price, which reduces the operational cost and helps balance the electricity system.

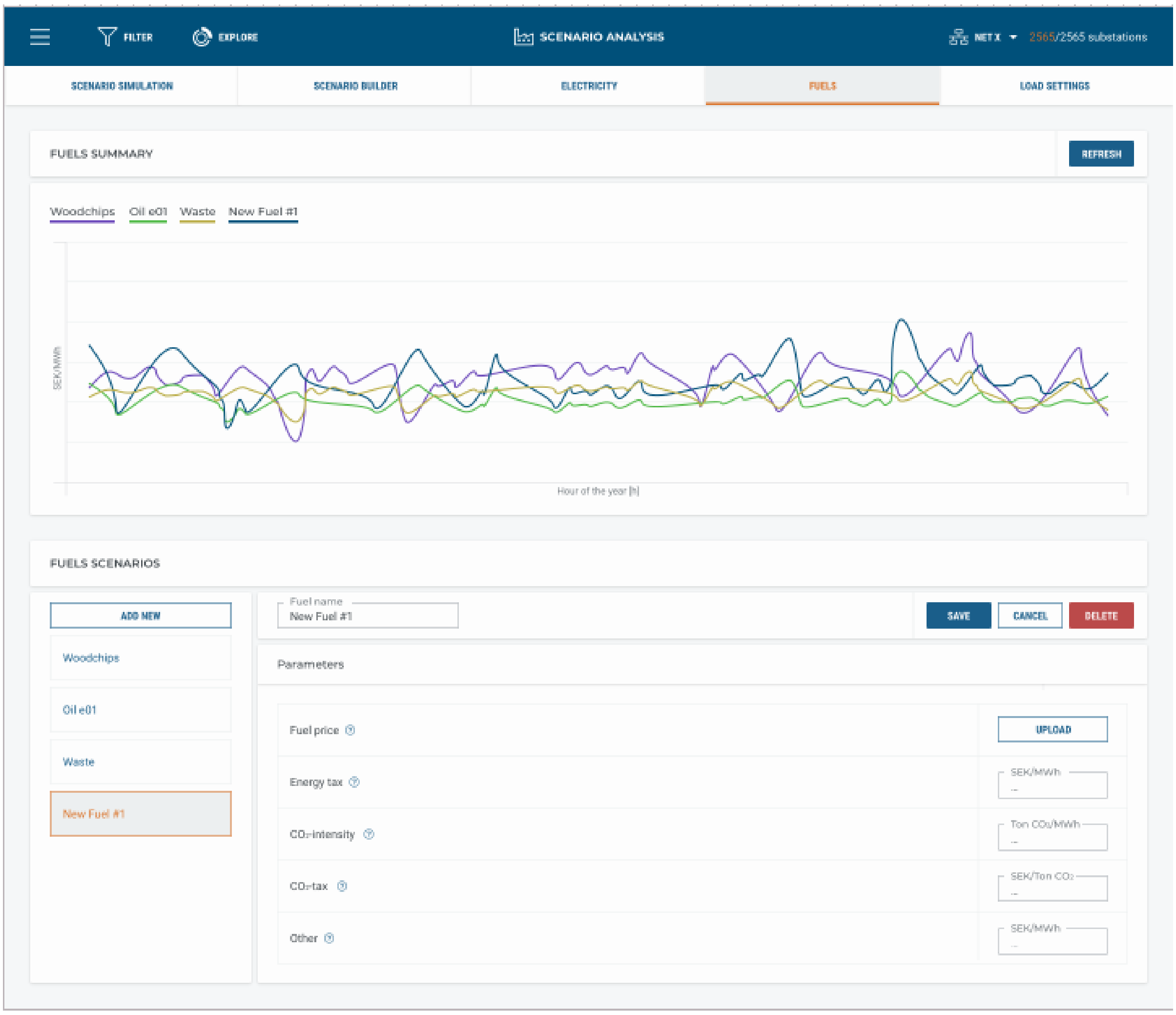
User interface

When using the Scenario Analysis feature to simulate different scenarios, a lot of different settings need to be made. First of all, the reference scenario needs to be set up. If the system already exists, this will be the reference system. All components with their respective parameters need to be input. An example of how this page, the *Scenario Builder* tab, might look is found below. On the same page, it is also possible to create other scenarios in the same way.

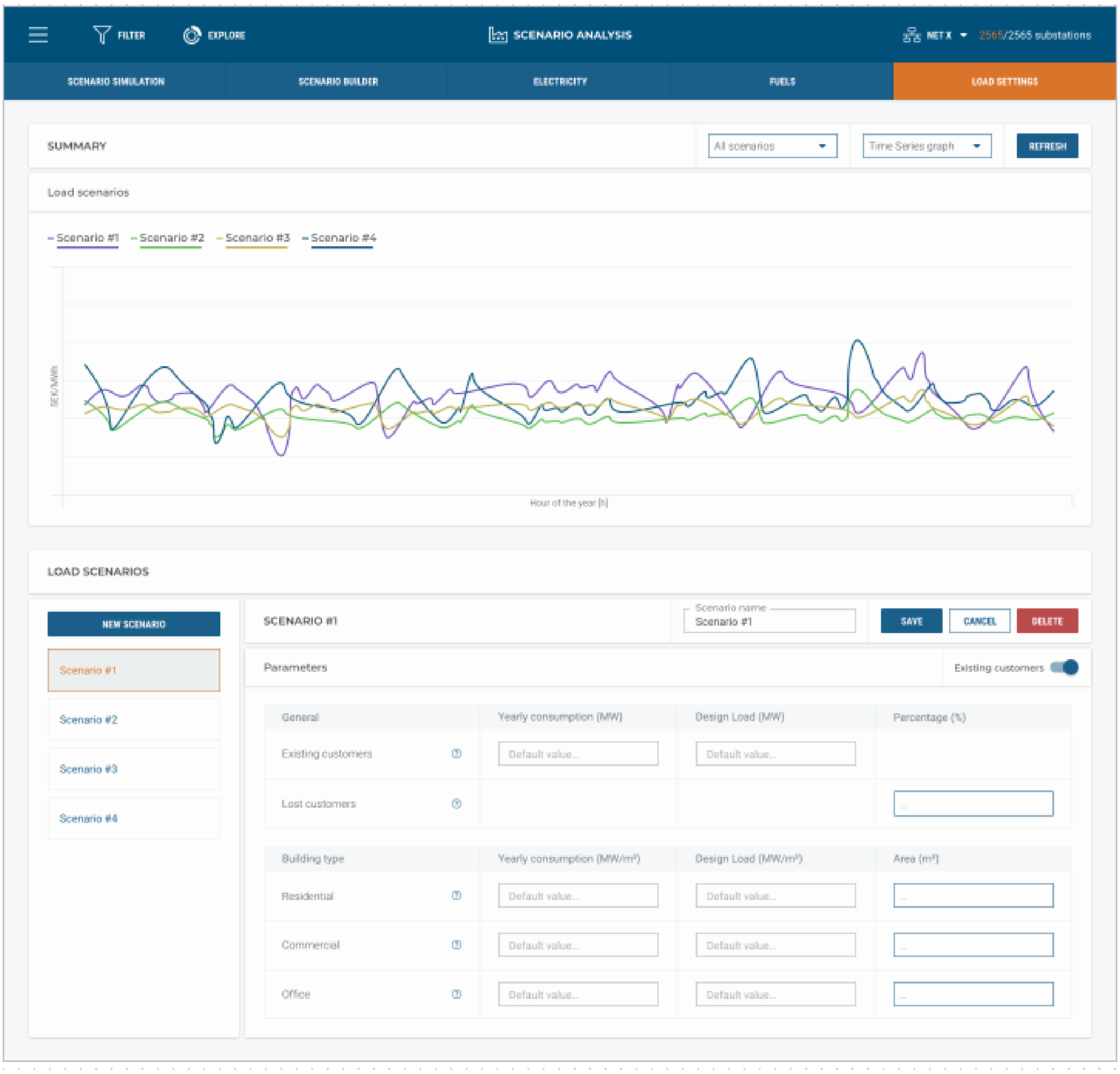


Different scenarios for electricity and fuels can also be created, and then used in the *Scenario Builder* tab. For the electricity scenarios, it is possible to either use historical prices, or import simulated future prices. Examples of how the *Fuel* and *Electricity* tabs might look can be found below.

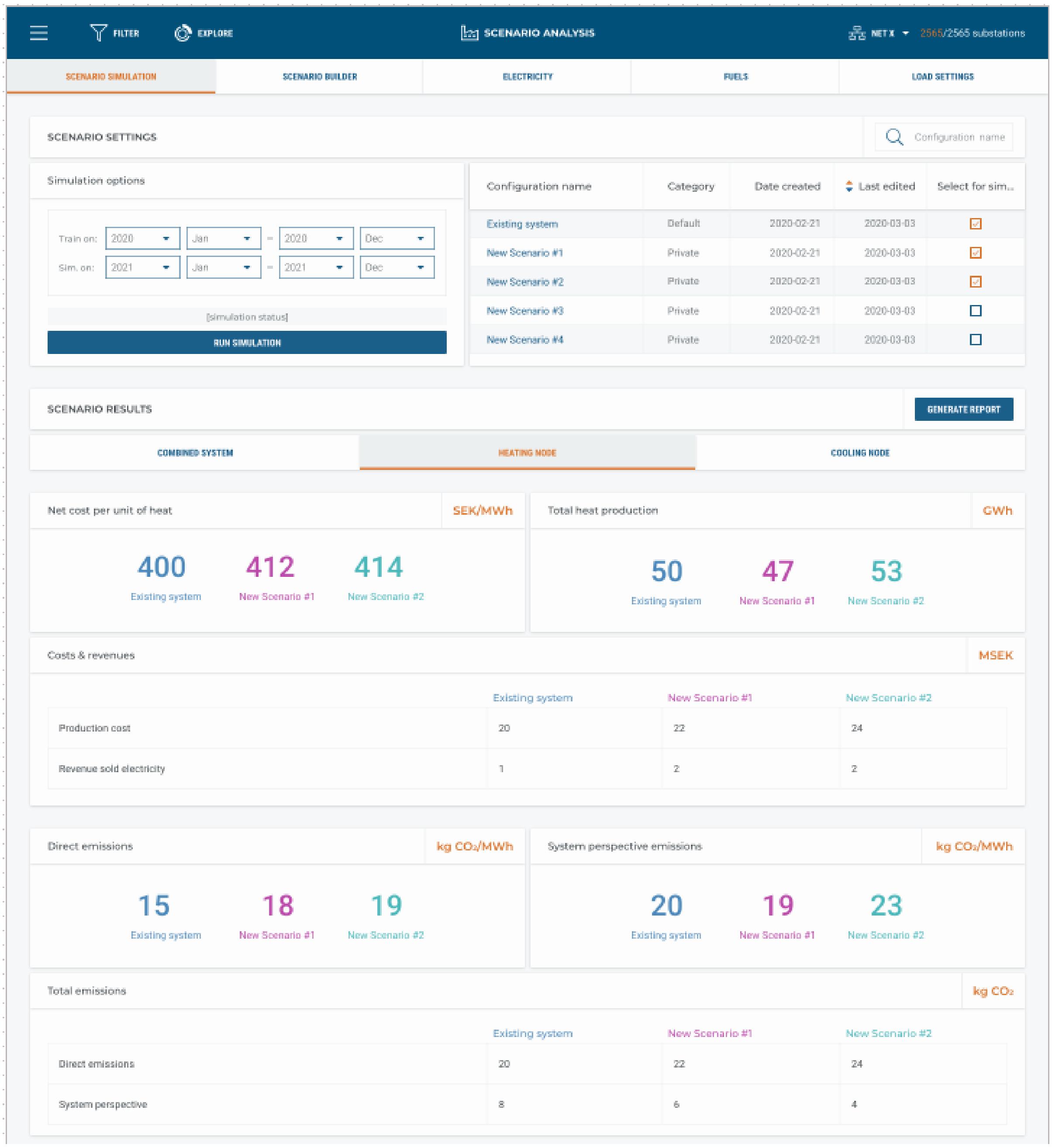


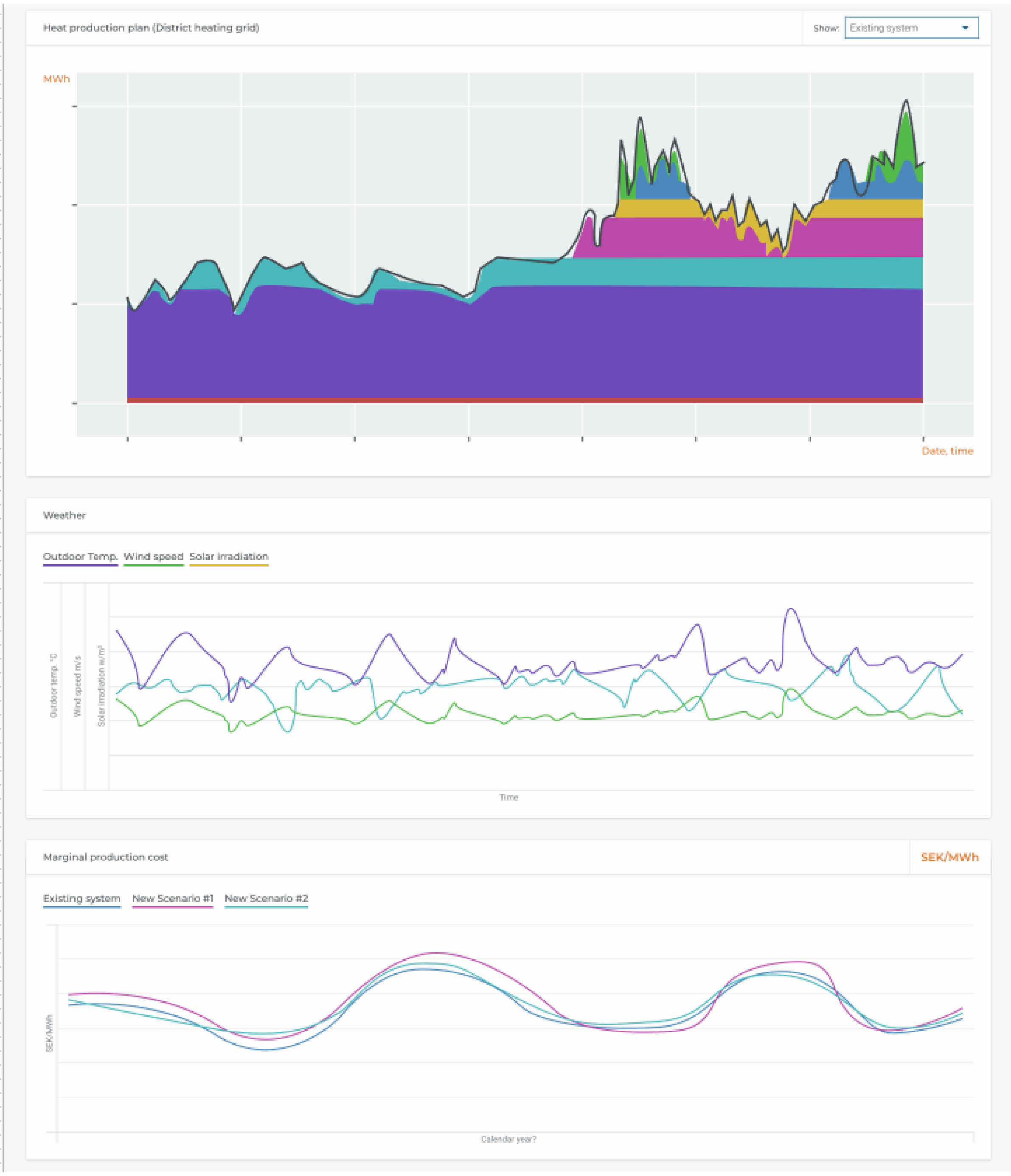


The rightmost tabs that are seen in the mock-ups are called *Load Settings*. If the analysis is for a non-existing network, a load profile for the network needs to be created. This can be done at the *Load Settings* tab, with help from reference buildings. The load for the reference buildings is already in the system and can be adjusted to fit the new network. If there is an existing system, that load can also be adjusted for new and/or lost customers. A mock-up for the *Load Settings* tab can be found below.



When all scenarios are created, the user goes to the *Scenario Simulation* tab. Input values needed are the training period and simulation period, and which scenarios to simulate. Then it is time to run the simulation, and when that is done, the result will be shown below. The result consists of some KPIs, for example, production cost, total heat generation, and emissions. Below the KPIs, there are a number of graphs and support numbers to further investigate the results. The user can evaluate the different scenarios, and if needed make changes and then do new simulations.


FILTER
EXPLORE
SCENARIO ANALYSIS
NET X
2565/2565 substations
SCENARIO SIMULATION
SCENARIO BUILDER
ELECTRICITY
FUELS
LOAD SETTINGS
SCENARIO SETTINGS
Configuration name
Simulation options
Train on: 2020 Jan 2020 Dec
Sim. on: 2021 Jan 2021 Dec
[simulation status]
RUN SIMULATION
Configuration name
Category
Date created
Last edited
Select for sim...
Existing system Default 2020-02-21 2020-03-03
New Scenario #1 Private 2020-02-21 2020-03-03
New Scenario #2 Private 2020-02-21 2020-03-03
New Scenario #3 Private 2020-02-21 2020-03-03
New Scenario #4 Private 2020-02-21 2020-03-03
SCENARIO RESULTS
GENERATE REPORT
COMBINED SYSTEM
HEATING MODE
COOLING MODE
Net cost per unit of heat
SEK/MWh
400 Existing system
412 New Scenario #1
414 New Scenario #2
Total heat production
GWh
50 Existing system
47 New Scenario #1
53 New Scenario #2
Costs & revenues
MSEK
Existing system
New Scenario #1
New Scenario #2
Production cost 20 22 24
Revenue sold electricity 1 2 2
Direct emissions
kg CO₂/MWh
15 Existing system
18 New Scenario #1
19 New Scenario #2
System perspective emissions
kg CO₂/MWh
20 Existing system
19 New Scenario #1
23 New Scenario #2
Total emissions
kg CO₂
Existing system
New Scenario #1
New Scenario #2
Direct emissions 20 22 24
System perspective 8 6 4


Heat production plan (District heating grid)
Show:
Existing system
MWh
Date, time
Weather
Outdoor Temp.
Wind speed
Solar irradiation
Outdoor temp. °C
Wind speed m/s
Solar irradiation w/m²
Time
Marginal production cost
SEK/MWh
Existing system
New Scenario #1
New Scenario #2
SEK/MWh
Calendar year?

Total electricity produced & consumed — MWh

Component	Existing system	New Scenario #1	New Scenario #2
CHP 1	20	22	24
CHP 2	8	6	4
Heat Pump	-16	-21	-18
Net production	4	7	10

Total fuel use — MWh

Fuel type	Existing system	New Scenario #1	New Scenario #2
Waste	100	110	120
Wood chip	83	80	78
Bio oil	20	18	16
[Fuel]	X	X	X

External connection — MWh

	Existing system	New Scenario #1	New Scenario #2
Import	-100	-110	-120
Export	83	80	78
Net Export	-17	-30	-38

Simulations for Silkeborg

Within this project, the network in Silkeborg was simulated with the Scenario Analysis Software. First, the network was set up as it is designed today, to use as the reference case. Then two alternative scenarios with demand-side flexibility were created: one scenario with only BITES, and one with BITES and solar PVs. A detailed description of the different scenarios, including results, is presented in the following sections.

The different scenarios were set up in the Scenario Analysis software. Historical demand data from the real network was used as the heat load for each scenario. All the different components that were needed for the different scenarios were added to each case. The electricity prices were also imported, and adjusted, to be used in each of the scenarios.

All scenarios were simulated, with the objective of minimizing the operational cost for the whole year. The outcome is the optimal heat production plan, for every hour of the simulated year, including some key performance indexes (KPIs) to be able to compare the different scenarios.

Reference case

Silkeborg 5GDHC network has 15 houses and a borehole connected to the grid. In the reference case, there is one heat pump (HP) per building. One of the heat pumps has COP 5, while the rest has COP 4,4. The borehole is modeled in a simplified way, as a heat source that is connected to the grid. There is no possibility of loading the borehole with excess heat. As electricity costs for the heat pumps, the spot prices for the correct area in Denmark are used. No add-on costs, like taxes or grid fees, were added to the spot price during these simulations since heat pumps are the only heat source. When simulating the reference case, no flexibility is used, and the heat demand of the buildings needs to be fulfilled directly from the heat pumps. Outputs from the simulation of the reference case are found in Table 1.

Table 1

KPIs for the reference case.

	2019	2020
Heat produced	138 600 kWh	139 500 kWh
Electricity consumed	30 910 kWh	31 140 kWh
Electricity produced	0 kWh	0 kWh
Operational cost	9 330 DKK	5 530 DKK

BITES case

The BITES case includes the same things as in the reference case, but with the addition that demand side flexibility can be used in the buildings. This is used by shifting the heat load from one hour to the next while utilizing the Building Inertia Thermal Energy Storage (BITES). By using flexibility in the building, heat production can be shifted to hours with lower electricity prices, which will result in lower operational costs. KPIs for the BITES case are found in Table 2.

Table 2
KPIs for the BITES case.

	2019	2020
Heat produced	127 800 kWh	131 500 kWh
Electricity consumed	28 500 kWh	29 360 kWh
Electricity produced	0 kWh	0 kWh
Operational cost	8 260 DKK	4 530 DKK

If the operational costs for the reference case and the BITES case are compared, it can be seen that introducing BITES results in a reduction of yearly operational costs by 12 % in 2019 and 18 % in 2020.

BITES + solar PV case

In the third case solar PVs were also added to all of the houses. All of the values for the solar panels were estimated based on other installations, and the purpose of the optimization, in this case, is to give a rough idea of what value it can bring to the network. The selling price of the produced electricity is set to 40% of the buy price of electricity. KPIs for the BITES + solar PV case are found in Table 3, note that no investment costs for solar panels are included.

Table 3
KPIs for the BITES + solar PV case.

	2019	2020
Heat produced	127 800 kWh	131 500 kWh
Electricity consumed	28 500 kWh	29 360 kWh
Electricity produced	244 500 kWh	244 000 kWh
Operational cost	- 11 960 DKK	- 8 060 DKK

Comparing the different simulated cases

A comparison of the cost per unit of heat produced, for the three different cases, for both year 2019 and 2020 can be seen in Table 4. It can be seen that the BITES case has a lower cost per unit of heat produced, than the reference case, for both 2019 and 2020. The savings with using BITES is larger both in terms of relative cost, and direct cost, in the year 2020, even though the total cost was smaller. This might be because of larger fluctuations in electricity prices in 2020 than in 2019.

The solar PV case is difficult to compare to the other cases since the income from the sold electricity is so large. The income from the sold electricity is much larger than the cost for the bought electricity, and the next step would be to compare the yearly savings with the investment cost of solar PV, to see if the investment is profitable.

Table 4

Cost per unit of produced heat for the different cases.

	2019	**2020**
Reference case	67,29 DKK/MWh	39,65 DKK/MWh
BITES case	64,68 DKK/MWh	34,44 DKK/MWh
BITES + solar PV case	-93,60 DKK/MWh	

In Figure 1, the aggregated heat demand for 6 days is shown with the black line. In the reference case, the exact amount of heat needed every hour is produced with the heat pumps. How the heat is produced in the BITES case can be seen by the blue area in the same graph. The production does not match the consumption perfectly, and the shift is because of the use of BITES. When the demand is higher than the production, the building is “discharged” and when the demand is lower than the production the building is “charged”. This charging and discharging are based on the operational costs in the network, which in this case correlates with the electricity prices. The electricity price is the red line in the same graph.

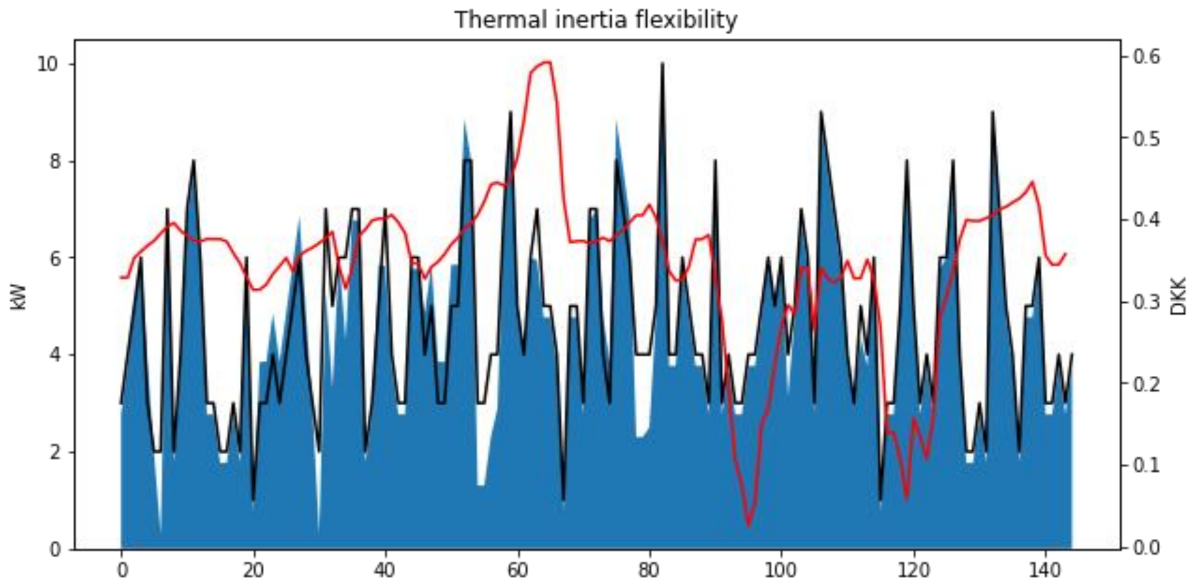


Figure 1: Six days of aggregated heat demand (black line) and corresponding aggregated production (blue area) for the BITES case. On the right Y-axis, the electricity price (red line) for the same period is shown.

Conclusions and summary

When simulating the network in Silkeborg, with and without demand-side flexibility, it can be seen that the operational cost is reduced when using BITES. The reduction needs to be compared to the installation cost of a smart control system in the network before it is clear if it is profitable or not. What is clear already now, is that with this type of tool, where the user can simulate many different scenarios for the same network, it is easy to evaluate what cost reduction BITES can give. Suppose not all buildings are suitable for using BITES. In that case, it will also be possible to run the simulation again, with for example only half of the BITES capacity, to see how that will affect the operational cost. It should also be stressed that the simulations are made for 2019 and 2020, which had significantly lower electricity prices than what we have seen so far during 2022. The variation in electricity price is also significantly higher during 2022, and saving potential from BITES is heavily correlated with the variation in electricity price. Saving potential today could therefore be magnitudes higher.

Since little was known about the houses when the simulations with the solar PVs were made, many estimates about size, angle, and direction were made. But with a tool like this, it can still be valuable input. If the selected input parameters for the solar PVs give a substantial income, like in the simulated case in this report, it can be understood that a solar PV installation might be worth looking into. When more exact information has been gathered about the roofs of the houses, a new simulation can be made to find out what the exact savings of installing solar panels can be.

Using the Scenario Analysis software with BITES on the Silkeborg network gives the conclusion that it is worth controlling the grid depending on the electricity prices. Without BITES, there is nothing that can be controlled in the network, all heat pumps must react fully to the heat load of the houses.

It will also be valuable to look into how the design load of the system, or single substations, can be reduced by using BITES. If it is possible to reduce the design load or get a better understanding and control of it, it might lead to that the installed capacity in the network can be reduced, which will be cost-efficient.

Simple examples for testing out the Scenario Analysis software have been used in this project. It still gives valuable insight into how different parameters affect the operational costs of a network, and the different parameters could be changed with very little effort from the user. The next step would be to try and simulate more complex networks, or more complex control of the network, in order to fully show the potential of the Scenario Analysis software.