
CampusEnergy2021
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Feb. 16-18 | CONNECTING VIRTUALLY

Fortum Tartu City, Estonia

5th Global District Energy Climate Awards Winner in 2017

Strategic Feasibility study to enhance the design of the large scale district energy power, cooling and heating system for future demand, optimizing the utilization of biomass and waste energy sources to improve profitability and lower emission using state-of-the-art modeling software solutions

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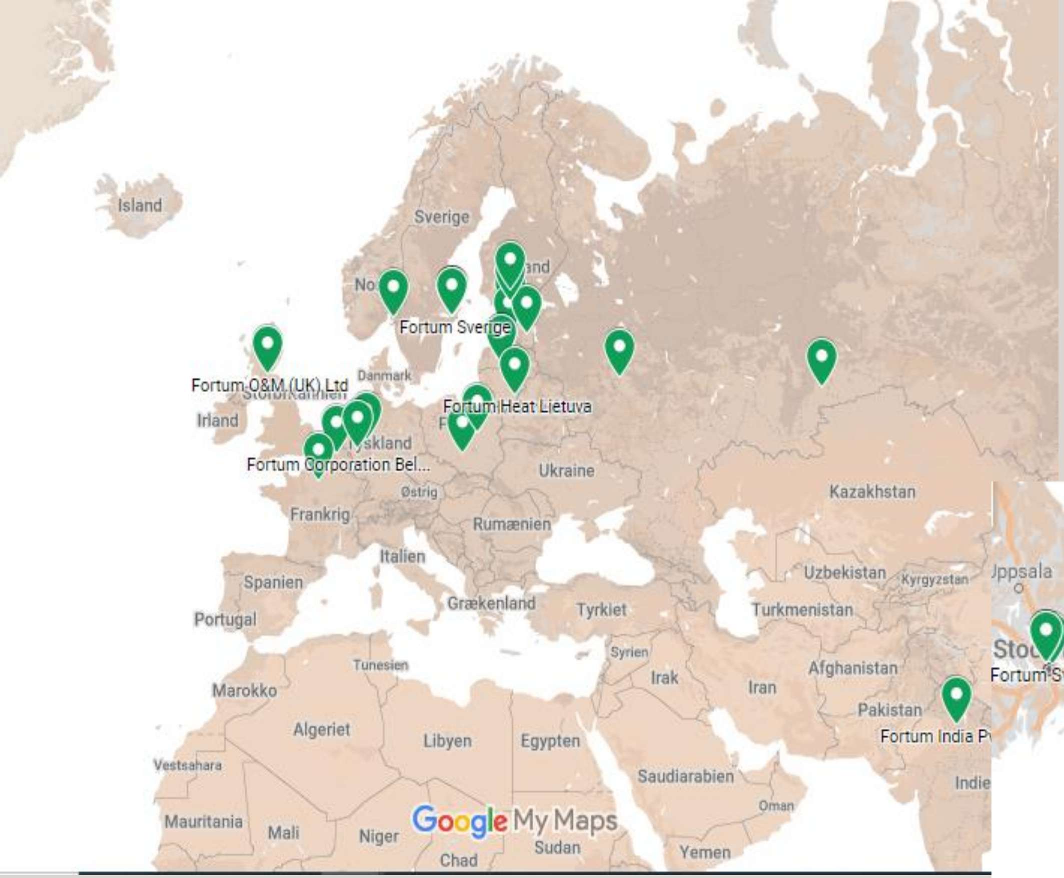
fortum Tartu
REO
NIRAS

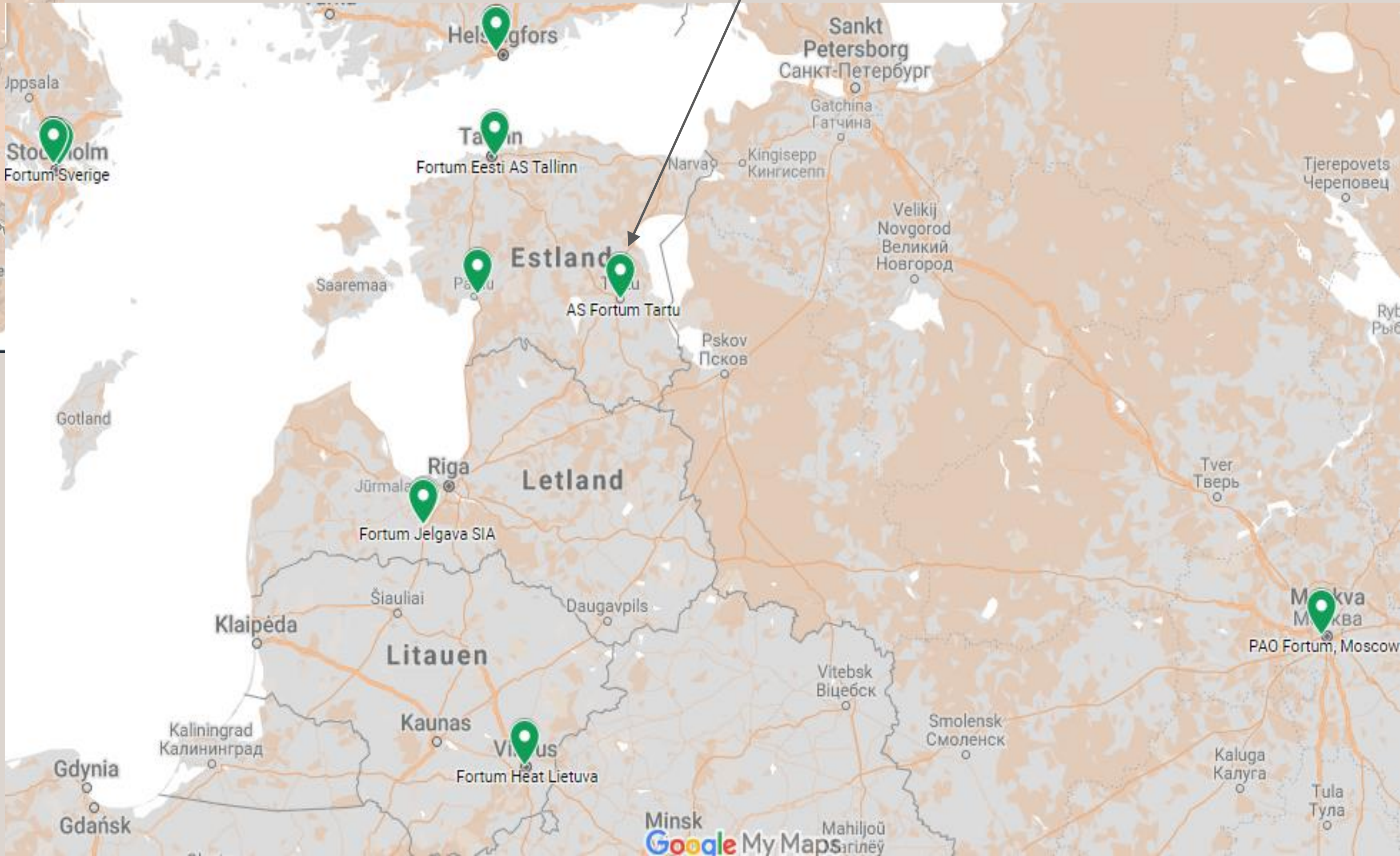
Agenda

Fortum district energy system at the Tartu City, Estonia.

- Introduction to Fortum and the Tartu City district energy system
- Strategic Feasibility Study Project Bckground
- Approach - Tools and Data
- Solution Options and Results
- Lessons Learned



Fortum Energy
Tartu City, Estonia



Fortum - www.fortum.com

- Operations in 10 countries, with some 8,000 energy sector professionals.
- Worldwide, more than 2.5 million customers,
- 150+ power, heating and cooling plants,
- Annual Revenue: USD $6+ Billions
- Global energy production in 2019:
  - 76.3 electricity (TWh)
  - 26.4 heat (TWh)
  - 59% of electricity production CO_2 free

Tartu District Energy System - History

- DH established in Tartu in 1967, owned by the State then by the municipality. In 1995, after the liberation from the USSR, the system participated in a renovation program financed by the World Bank and the EBRD35 switching fuel sources from gas and oil to local and renewable sources, namely peat and biomass. In year 2004, DH went through a privatization process and became part of the Finnish company Fortum Heat and Power OY.
- Technology and innovation highlights from 2008 to 2016:
- 2009 Tartu combined heat and power (CHP) plant fuelled by biomass and peat was commissioned.
- Between 2009 and 2014 the district heating (DH) system continued expanding, mainly through the acquisition of another local DH system in 2013 in the “Tamme” area (90 GWh of sales, 3 production units, 34 km pipeline) and the installation of new peak capacity and closing of old boiler house in the city centre.
- In 2014, the development of district cooling (DC) projects started and the first DC plant was commissioned in May 2016, becoming the first DC network in the Baltics and Eastern-Europe.
- In 2015 tailored made DH and DC solution for customer Estonian National Museum.
- In 2016 tailored made full DH and DC solutions for customer Lõunakeskus Tradepark.
- In 2016 automatic smart meter readers installed to 72% of customers.
- Between the period 2008 to 2016 CO_2 emissions have been reduced from 123553 t to 89023 t. District cooling will be environmentally beneficial by reducing CO_2 emissions by 52 % (2700 ton/year) compared to the customers own alternative.

DH market share	50 % of buildings (75 % citizens) Population of the Tartu City: 93,000
Heating & cooling capacity	DH: 328 MWt/1,115 MMBTU DC: 13 MWt/3,705 Tons
Heat &Cooling production	DH: 500 GWh/year DC: 1.3 GWh/year
Km network (double-pipe)	DH: 173,5 km/110 miles DC: 1,8 km/1,1 miles
Heat network losses (%) in production	2008: 15,2% 2016: 10,8%
CO2 emissions (heating)	131 kg/MWh

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Project background

Fortum Tartu City, Estonia – Baseline district energy system

Generates and distributes district energy – power, heating and cooling - to residential, commercial and industrial customers with a peak of 270MW_e and 200 MWt. Using biomass, natural gas and flue gas from the CHP – 10 plants in total.

Due to the end of subsidies for producing electricity, Fortum Tartu intend to reduce the use of natural gas as much as possible (as well as reducing CO_2 emission) by using more waste energy and store the heat from the CHP production for more efficient usage. The city is growing significantly and hence the energy demand.

Trigeneration – the energy system of the Tartu City includes production, transmission and distribution of electricity, heat and cooling: Combined heat and power (CHP production); Heat only production (boilers, heat pumps); Cooling (heat pumps, compressor chillers)

NIRAS won the strategic feasibility study project due to the comprehensive mix of experience of using state-of-the-art modeling tools for hydraulic analysis as well as energy and cost-benefit modeling, energy technology including thermal energy storage (both steel tank and seasonal PTES), biomass and waste energy utilization.

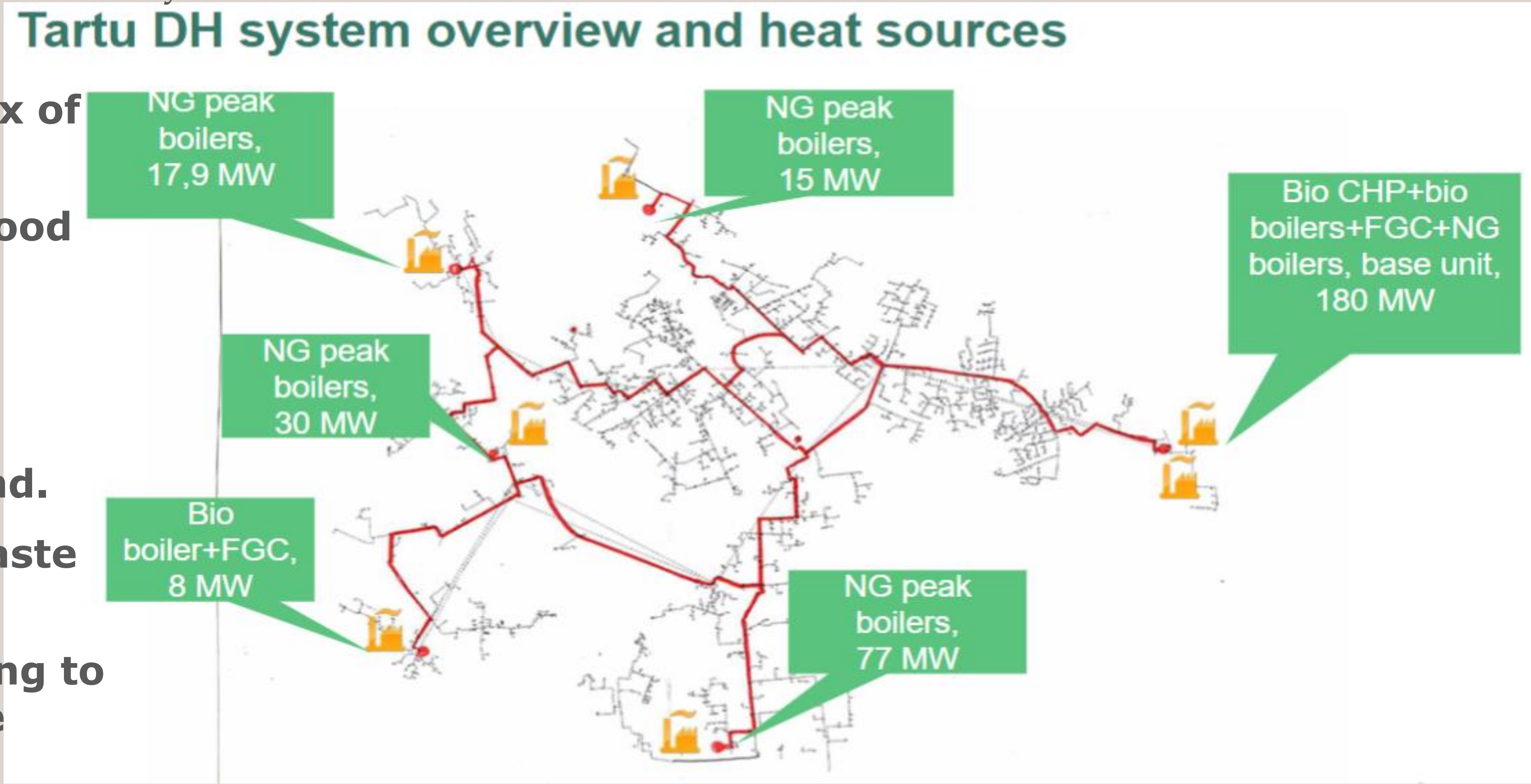
Existing sources

Located around the city

Plants with mix of fuels:

- **Biomass (wood chips)**
- **Peat boilers**
- **Natural gas**
- **Flue gas cond.**
- **Potential waste heat**

Not all are going to be there in the future!

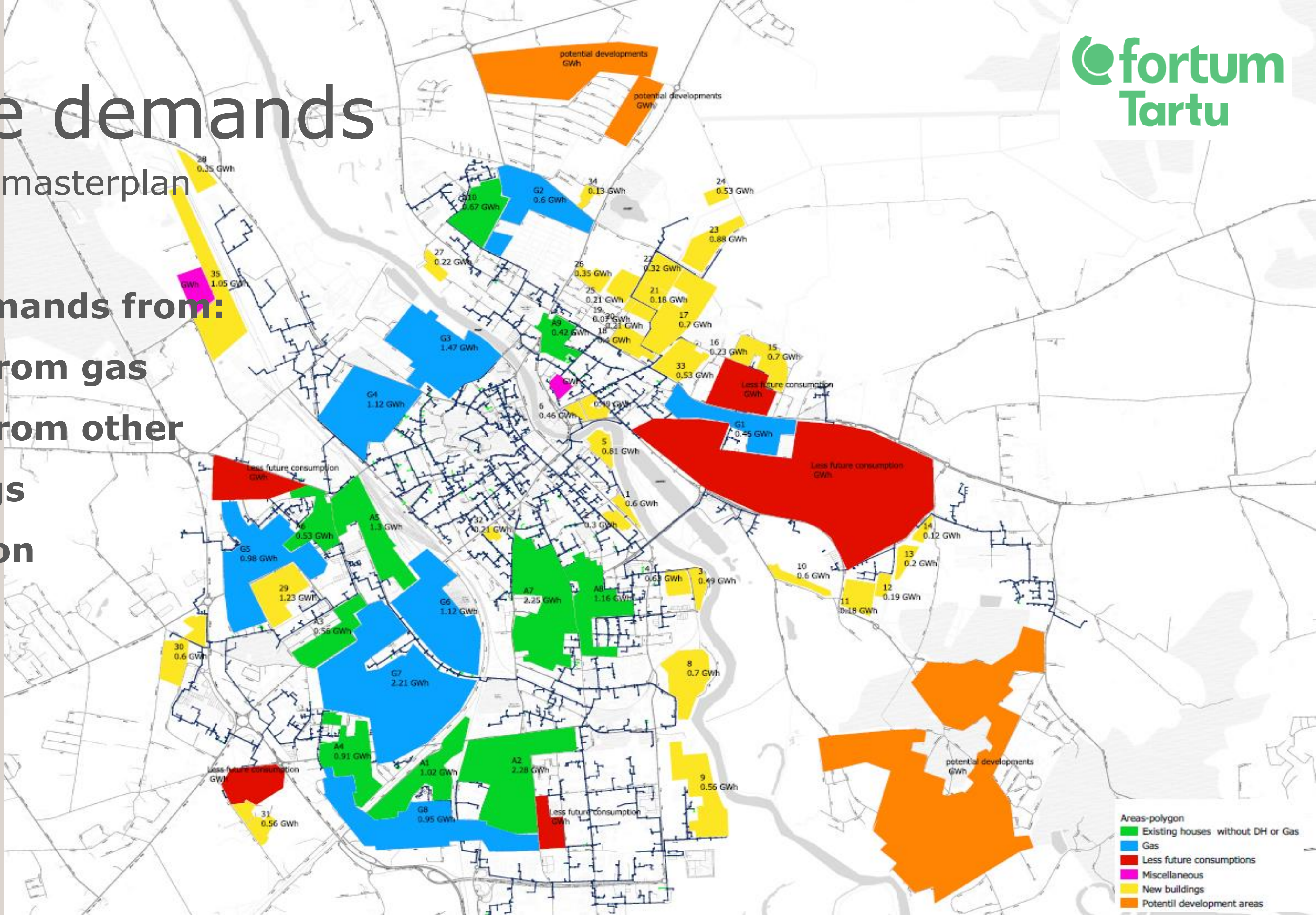


Future demands

Included in masterplan

Future new demands from:

- **Conversion from gas**
- **Conversion from other**
- **New buildings**
- **City expansion**



Fortum's primary scopes

- Masterplan development – plans for the future heat supply without electrical subsidies.
- Production planning / operation strategy – optimizing the production according to heat demand electricity prices and specific conditions (storage, production units,..) .
- Feasibility study/investment analysis for future production capacity and storage opportunities.
  - Testing different storage opportunities (daily, seasonal etc.) and sizes.
  - Based on annual production costs, investment and energy conversion.
- CO_2 emission analysis (CO_2 reduction and comparison to be included)

Technical approach

Real historical data received for both production and distribution being used to create a baseline for the cost-benefit model and hydraulic master model.

Building a hydraulic model using GIS data to reflect various seasonal situations and determine hydraulic bottlenecks now and in the future.

Building a model of existing and future production units – techno-/economic analysis - to reflect the actual production and distribution cost.

Applying estimated future demand to both models

Create actual, near and long-term scenarios for both economic and hydraulic model

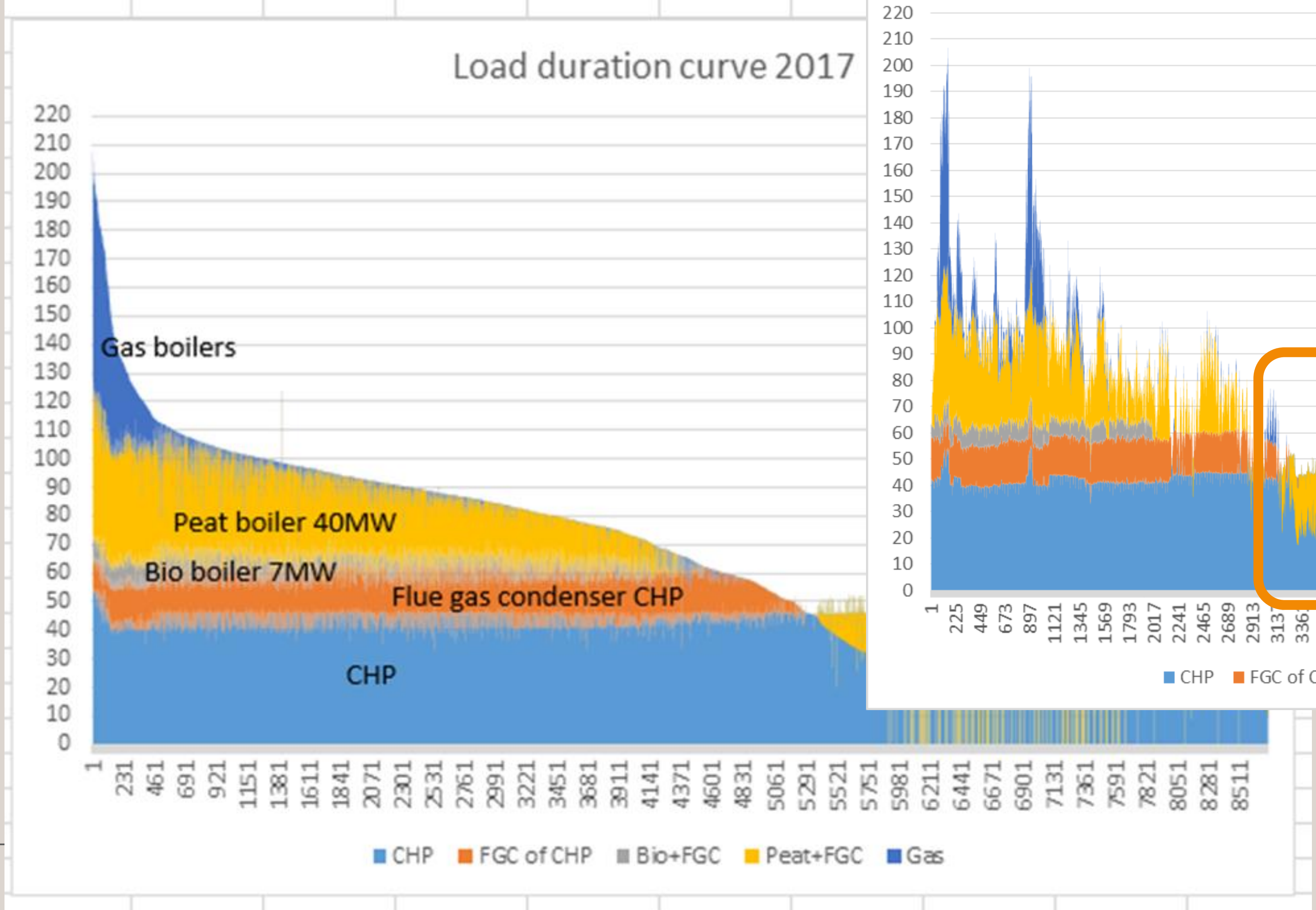
Test various possibilities for cost optimization and validate or reject using the hydraulic models.

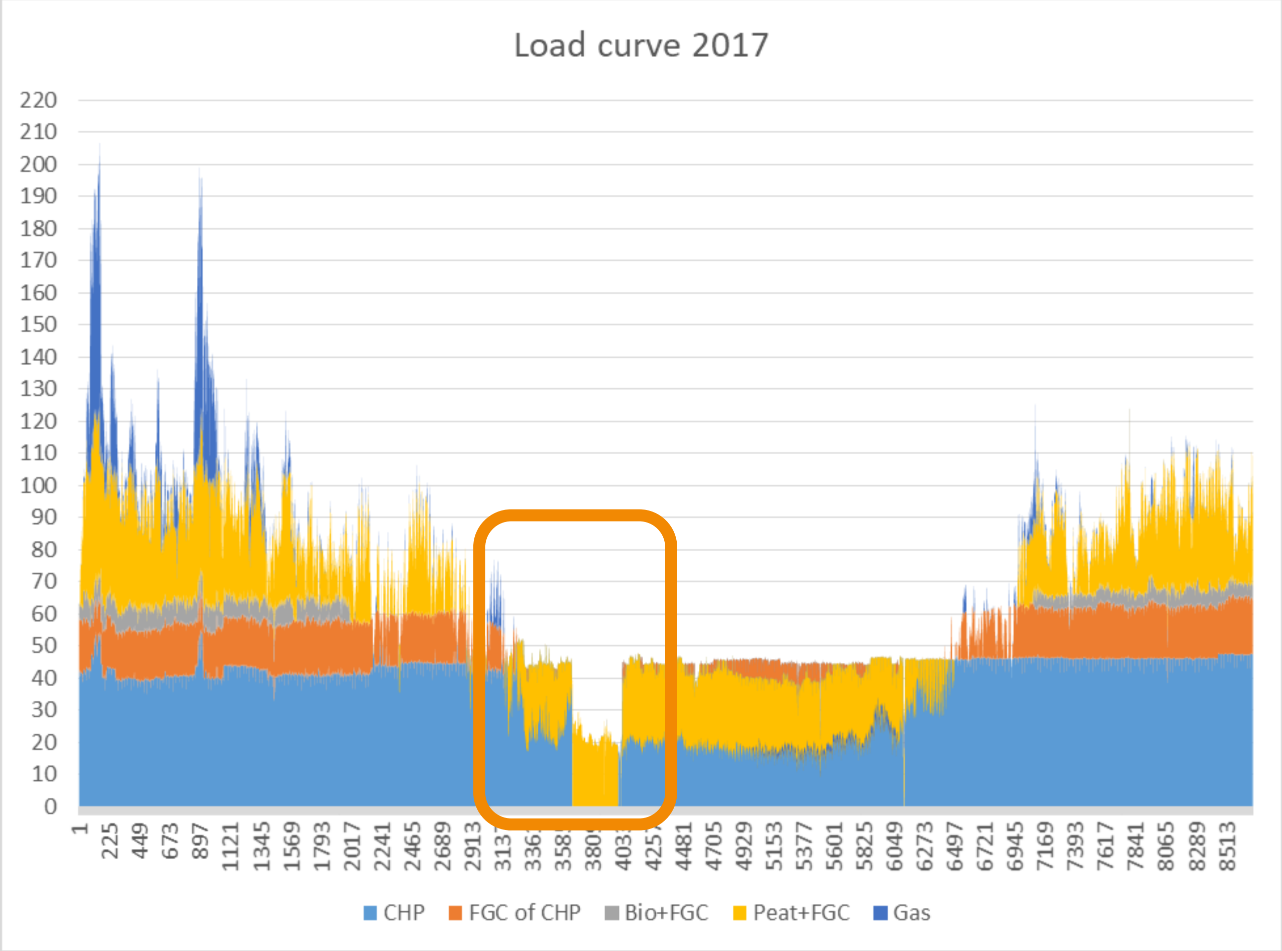
Applying possible waste heat sources to both models

Comparison of different scenarios and sensitivity analysis.

Historical data

As is production loads - Baseline





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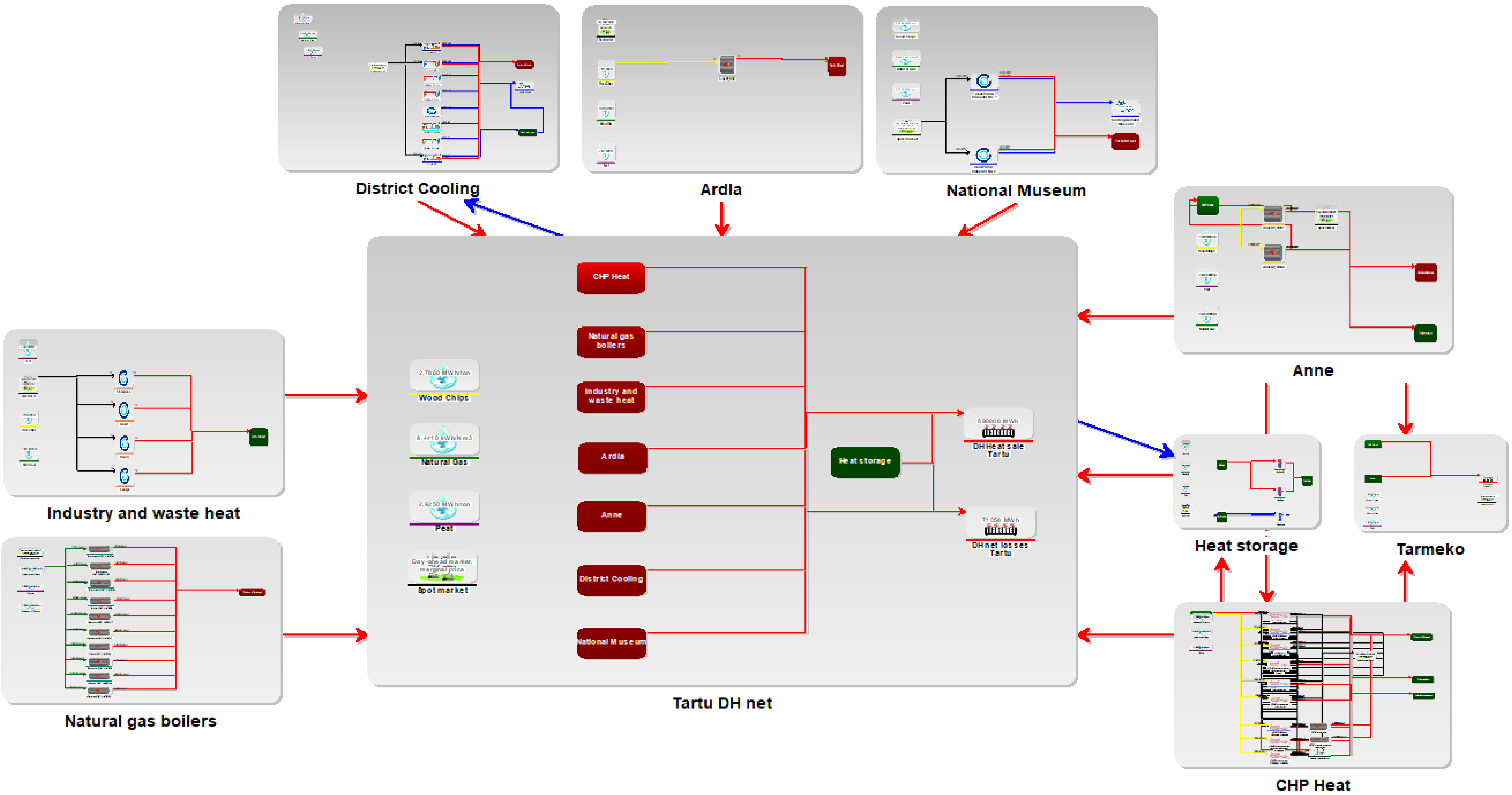
Tools used

energyPro technology / cost-benefit model

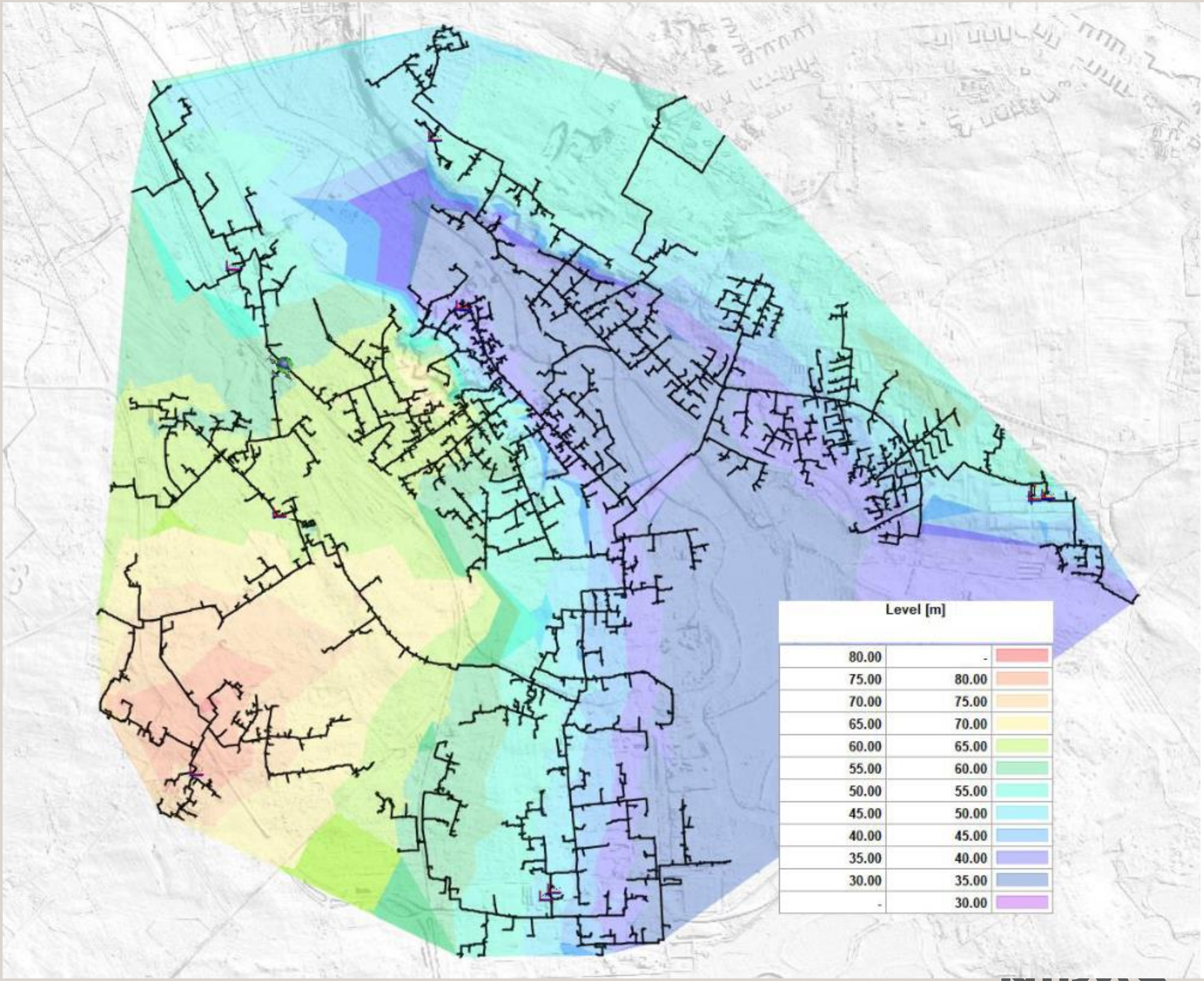


Tools used

Termis hydraulic model

A hydraulic master model was designed, built and calibrated using historical production and demand data.

Operational limitations were applied and hydraulic limitations were identified to be taken into account for the future analysis.



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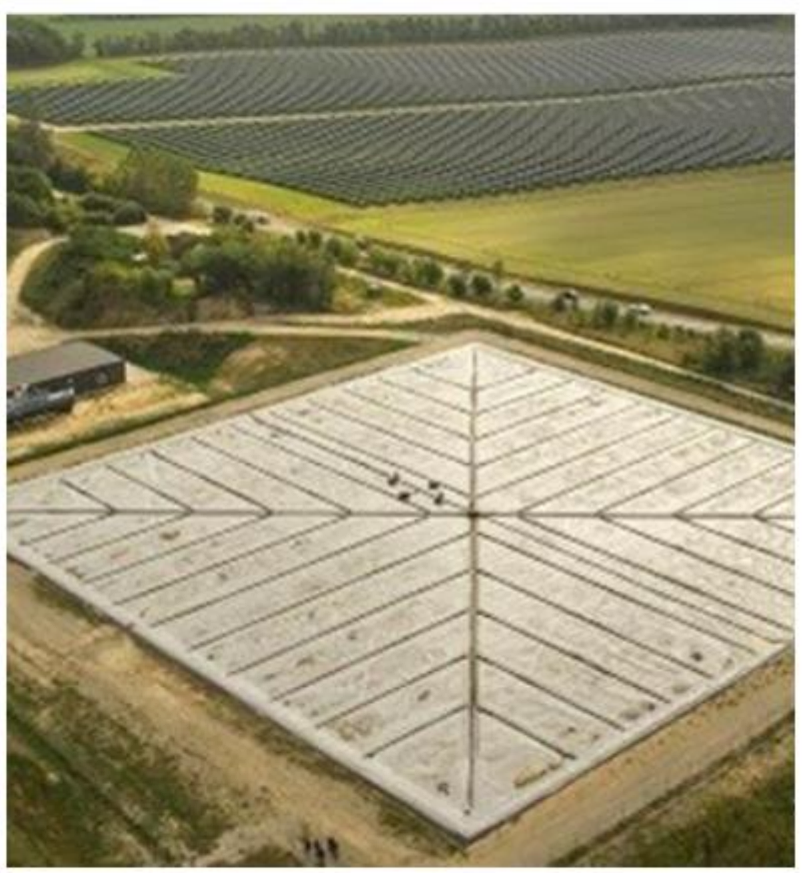
Pit Water Storage PTES

energy Pro calculation

What-iF Scenarios:

- 200000m³ + 400000m³ (52,8 / 105,6 MGal)
- Years 2021 + 2030 were simulated.
- Pricing estimates for year 2030 – sensitivity for various uncertainties was calculated.
- Only CHP plant and biomass are able to charge storages –> reducing possible location of the PTES
- No limit on charging/discharging PTES – so **what about hydraulics distribution?**
-



Dronninglund district heating utility in Denmark is the creator of one of the world's largest solar heating systems. A "reservoir" by 91x91 m / 300x300 ft water with a temperature in the 61,700 m³/ 16,2 mio gallons pool reaching app 90°C/ 195°F stores the solar energy from summer to winter.

https://www.niras.com/projects/great-potential-in-new-solar-technology/

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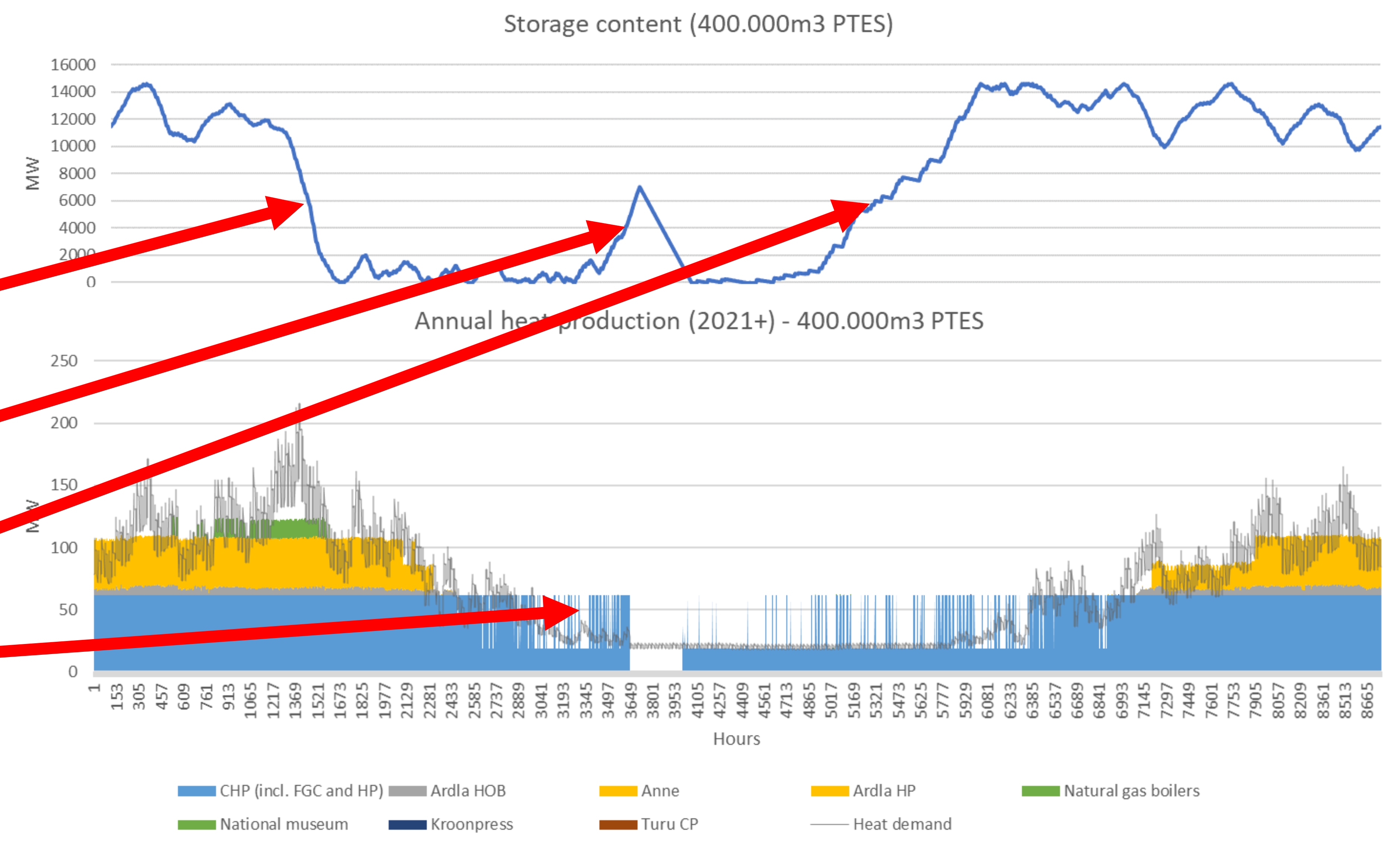
PTES

Utilization

Over the year a PTES can hold the energy between seasons:

- Discharging for summer -reducing usage of gas.
- Charging for CHP maintenance
- Charging for winter
- Utilized when electrical price is high



Thermal Energy Storage TES

energyPro calculation

What-If Scenarios:

- 5.000m^3, 10.000m^3 and 20.000m^3 (1,32 / 2,64 / 5,28 MGal)
- Location is bound as only CHP plant and biomass are able to charge storages – **are there alternative possible locations**?
- dT estimated 35°C / 63 °F
- 95% of the energy content can be utilized
- No limit on charging/discharging capacity –**is that possible hydraulically**?

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TES

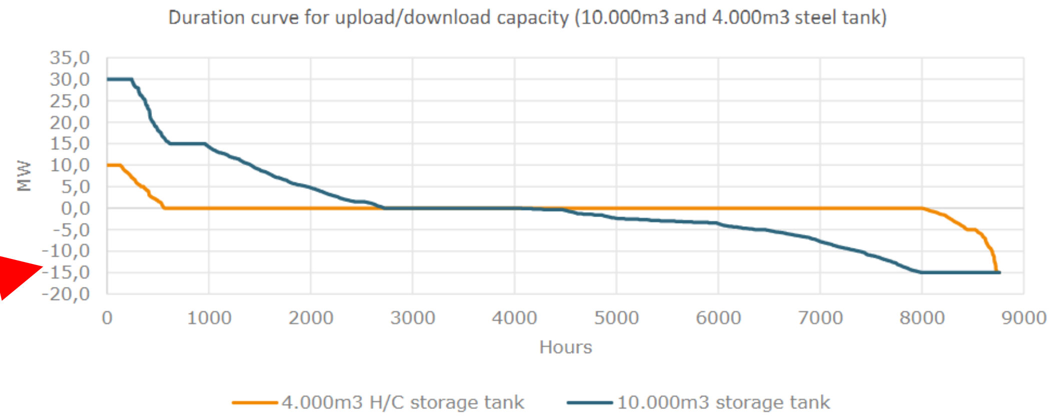
$10.000m^3 + 4000m^3$ / 2,64 + 1,05 MGal

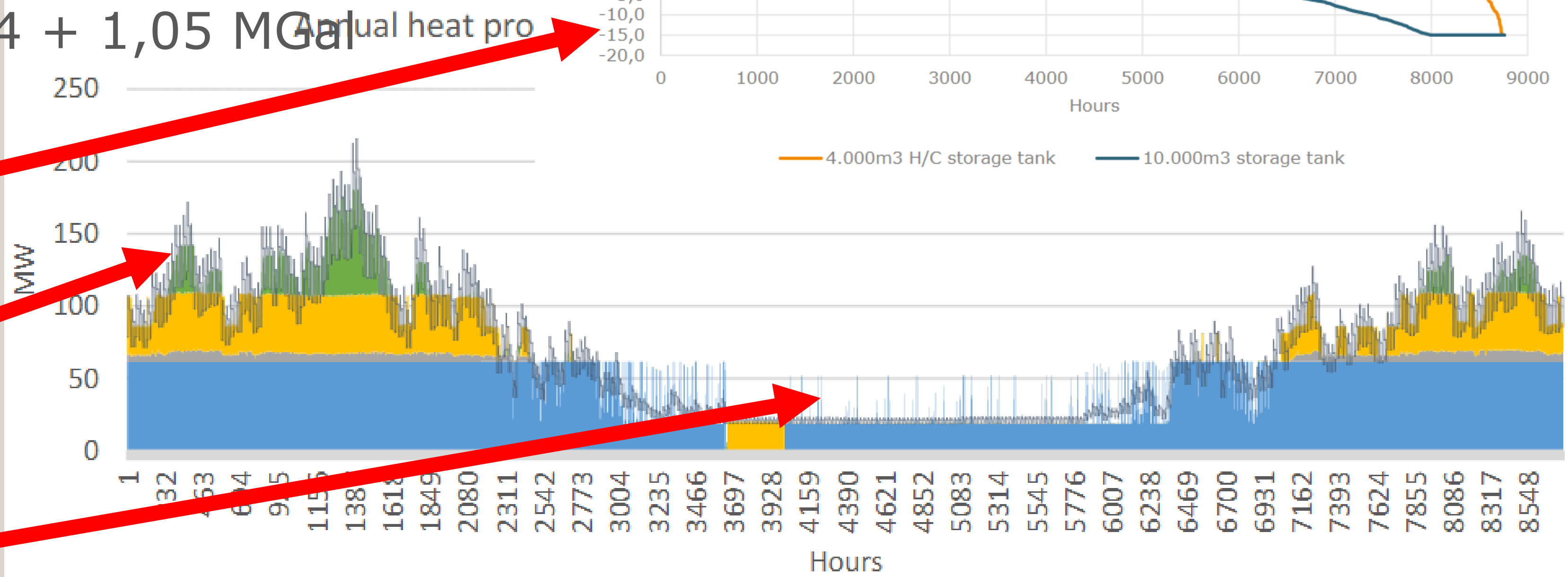
Over the year a TES is frequently used.

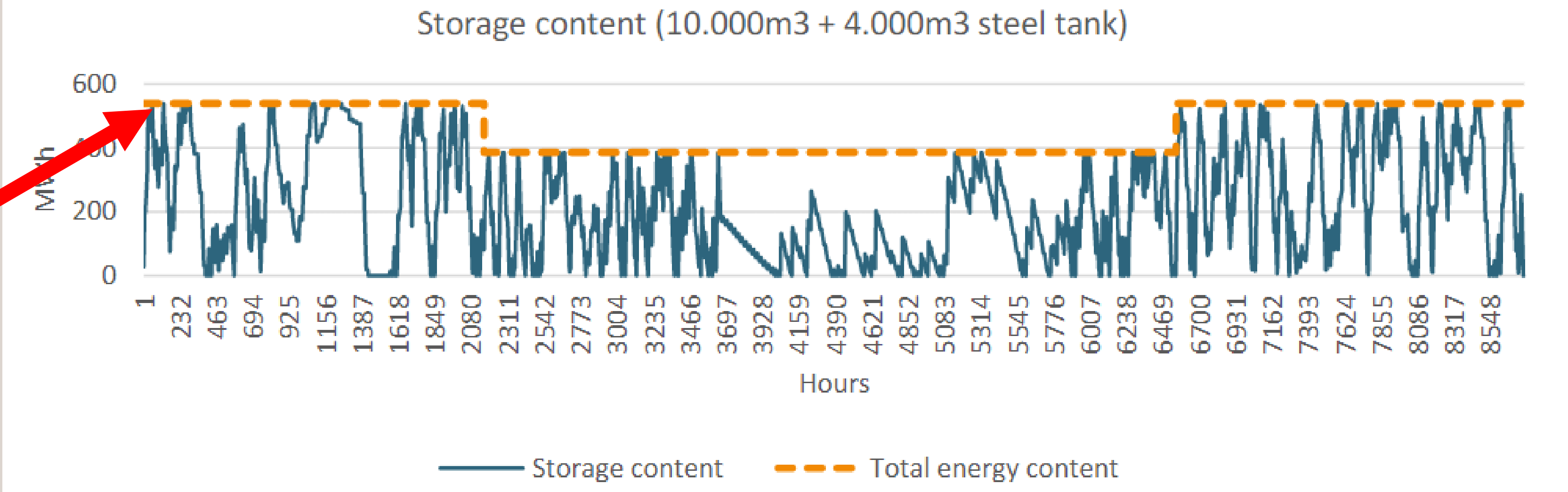
Reducing usage of gas in the winter peaks.

In the summer electricity can be produced when price is high.

During winter the CHW TES is used for hot water giving higher storage capacity.







Cost estimates

And CO_2 reduction

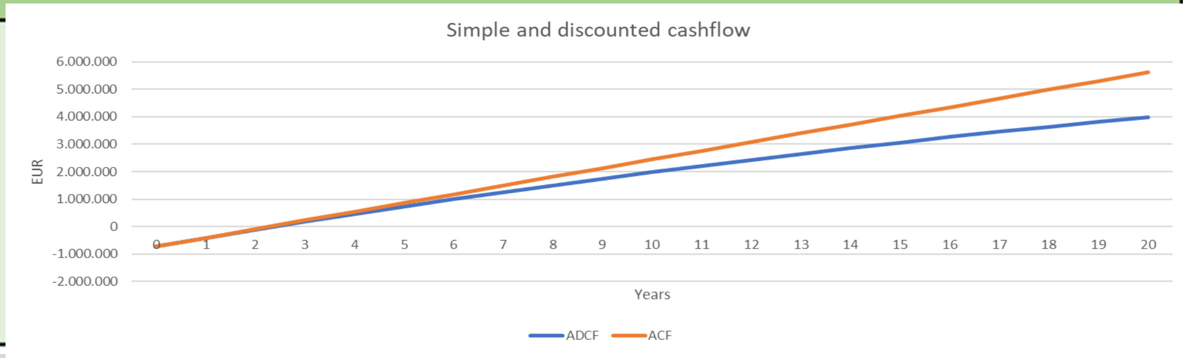
PTES and TES were evaluated with respect to economy, CO2 emission and payback time.

Eventually a 10.000m³ / 2,6MGal (+4.000m³ / 1,05 Mgal cooling tank during off-season) was chosen due to low investment and short payback time.

Carbon emission reduction is also calculated and included in the economical

Storage Calculations (Model 2021+)

Storage specifications and simulation		Reference	Steel tank			Pit storage	
Storage size	m³	-	5.000	10.000	20.000	200.000	400.000
Utilization rate	%	-	95%	95%	95%	90%	90%
Energy content of storage (multiplied with a utilization rate)	MWh	-	193	386	771	7.308	14.616
Hours with upload capacity (>10MW for TTES and >40MW for PTES	Hours	-	1.406	1.417	1.558	114	205
Hours with download capacity (>10MW for TTES and >40MW for I	Hours	-	1.321	1.390	1.544	111	200
Annual heat production - rounded (incl. Tartu DH net, heat losses, greenhouses and Tameko)							
Heat produced by Anne bio boilers	MWh/Year	127.000	137.000	137.000	138.000	137.000	137.000
Heat produced by CHP (incl. FGC and HP of FGC)	MWh/Year	396.000	398.000	399.000	400.000	413.000	420.000
Heat from Ardla bio boiler	MWh/Year	24.000	24.000	24.000	24.000	24.000	24.000
Heat from DC (incl. national museum)	MWh/Year	1.100	1.100	1.100	1.100	1.100	1.100
Heat from industry (waste heat)	MWh/Year	300	300	300	300	300	300
Heat produced by natural gas boilers	MWh/Year	46.000	34.000	33.000	31.000	17.000	10.000
Increase in electricity production	%	-	0,4%	0,7%	1,1%	4,1%	5,8%
Economy							
Investment (heat storage)							
Cost for heat losses							
Annual operation costs (energyPRO)							
Annual operation savings (energyPRO)							
SPT (Simple Payback Time)							
DPT (Discounted Payback Time)							
NPV (Net Present Value)							
CO_2 emissions							
CO_2 reduction							



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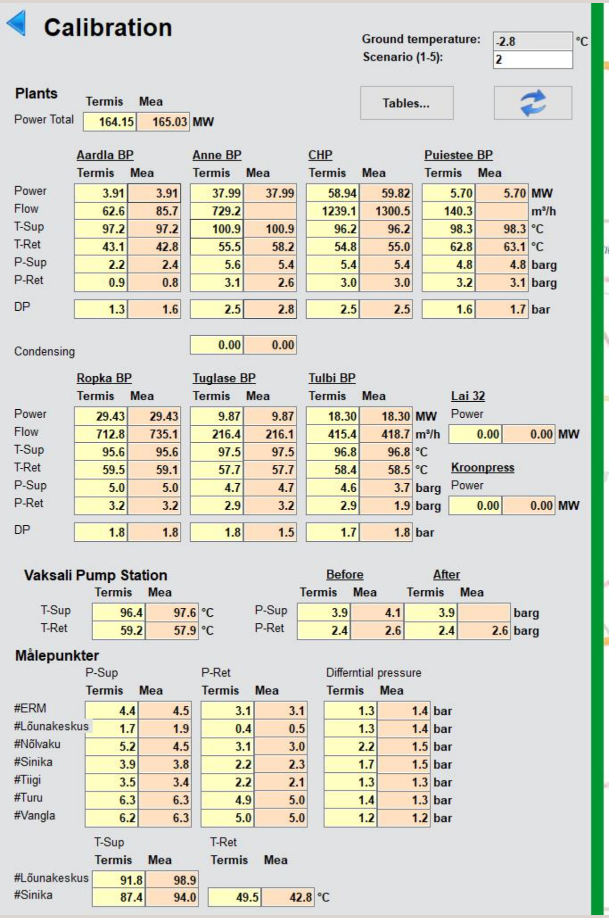
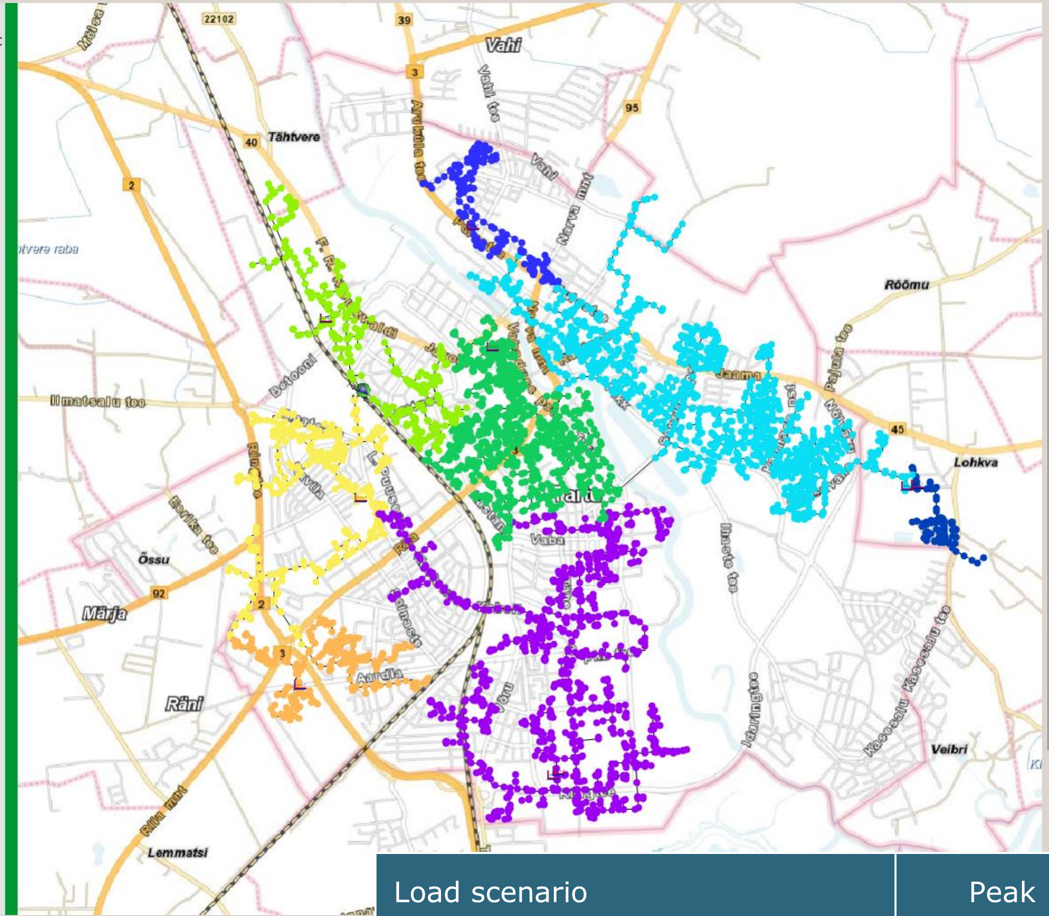
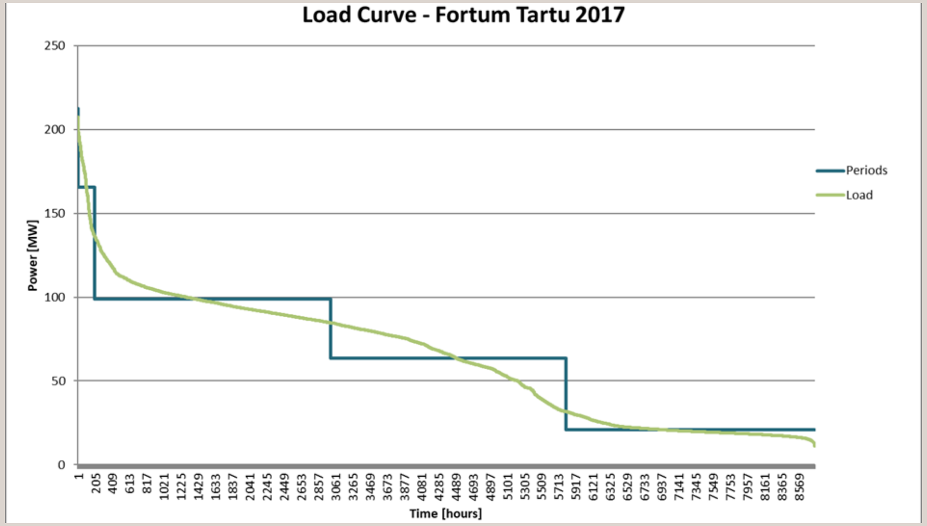
Hydraulic Model scenarios

For the years 2018, 2021 and 2030





5 various hydraulic scenarios configured with data from the duration load curve:



Load scenario	Peak	Cold winter	Mild winter	Spring/ Autumn	Summer
Duration [hours]	1.0	200.0	2.800.0	2.800.0	2.959.0
Average power production [MW]	212.5	165.4	99.0	63.7	20.9

Operational loads, pressure and temperatures

Hydraulic baseline scenario defined – as is.

Mild Summer

	Tartu
Total Production [MW]	22.86
Total Power Consumption [MW]	16.69
Total Heat Loss [kW]	6153.05
Total Power Pumps [kW]	57.37
Total Flow [kg/s]	
Total Cost [CU/h]	154.73
Min. Temperature, Supply [°C]	1.0
Max. Temperature, Supply [°C]	70.0
Min. Temperature, Return [°C]	-3.5
Max. Temperature, Return [°C]	58.8
Min. Temperature Change [°C]	-25.83
Max. Temperature Change [°C]	-10.00
Total External Power Accumulators [MW]	
Total Enthalphy Change [kW]	6163.24
Location for Max.Temperature, Supply [°C]	NO_12195
Mean Temperature, Supply [°C]	63.6
Location for Min.Temperature, Supply [°C]	NO_26419
Location for Max.Temperature, Return [°C]	NO_26548
Mean Temperature, Return [°C]	44.6
Location for Min.Temperature, Return [°C]	NO_25424
Actual Min. Pressure Change [barg]	-3.3
Actual Min. Pressure Change Object	NO_20753
Actual Max. Pressure Change [barg]	-2.3
Actual Max. Pressure Change Object	NO_10972
Actual Mean Pressure Change [barg]	-2.9

Mild Winter

	Tartu
Total Production [MW]	116.24
Total Power Consumption [MW]	108.44
Total Heat Loss [kW]	7793.79
Total Power Pumps [kW]	536.05
Total Flow [kg/s]	
Total Cost [CU/h]	1254.34
Min. Temperature, Supply [°C]	-9.0
Max. Temperature, Supply [°C]	73.0
Min. Temperature, Return [°C]	-19.0
Max. Temperature, Return [°C]	61.3
Min. Temperature Change [°C]	-46.50
Max. Temperature Change [°C]	-10.00
Total External Power Accumulators [MW]	
Total Enthalphy Change [kW]	7796.94
Location for Max.Temperature, Supply [°C]	NO_819
Mean Temperature, Supply [°C]	68.9
Location for Min.Temperature, Supply [°C]	NO_25424
Location for Max.Temperature, Return [°C]	NO_25289
Mean Temperature, Return [°C]	41.0
Location for Min.Temperature, Return [°C]	NO_25424
Actual Min. Pressure Change [barg]	-7.6
Actual Min. Pressure Change Object	NO_818
Actual Max. Pressure Change [barg]	-1.4
Actual Max. Pressure Change Object	NO_23056
Actual Mean Pressure Change [barg]	-3.8

Peak

	Tartu
Total Production [MW]	269.98
Total Power Consumption [MW]	258.50
Total Heat Loss [kW]	11461.87
Total Power Pumps [kW]	372.62
Total Flow [kg/s]	
Total Cost [CU/h]	7318.99
Min. Temperature, Supply [°C]	-14.4
Max. Temperature, Supply [°C]	115.3
Min. Temperature, Return [°C]	-24.4
Max. Temperature, Return [°C]	89.5
Min. Temperature Change [°C]	-77.50
Max. Temperature Change [°C]	-10.00
Total External Power Accumulators [MW]	
Total Enthalphy Change [kW]	11466.01
Location for Max.Temperature, Supply [°C]	NO_819
Mean Temperature, Supply [°C]	100.3
Location for Min.Temperature, Supply [°C]	NO_25424
Location for Max.Temperature, Return [°C]	NO_25289
Mean Temperature, Return [°C]	58.6
Location for Min.Temperature, Return [°C]	NO_25424
Actual Min. Pressure Change [barg]	-4.7
Actual Min. Pressure Change Object	NO_10103
Actual Max. Pressure Change [barg]	-1.0
Actual Max. Pressure Change Object	NO_9249
Actual Mean Pressure Change [barg]	-2.4

Hydraulic model - What If scenarios

Hydraulic analysis for a TES – a digital twin tool

The hydrailic models were updated and applied future demands for 2021 and 2030 to reflect how operation will be with a TES.

- Scenarios setup to cover one years production, operation and demand. The scenarios are used for:
  - Dimensioning new pipes and pumps to deliver the required loads
  - Optimizing operation for using TES best possible
  - Renovation planning for existing piping

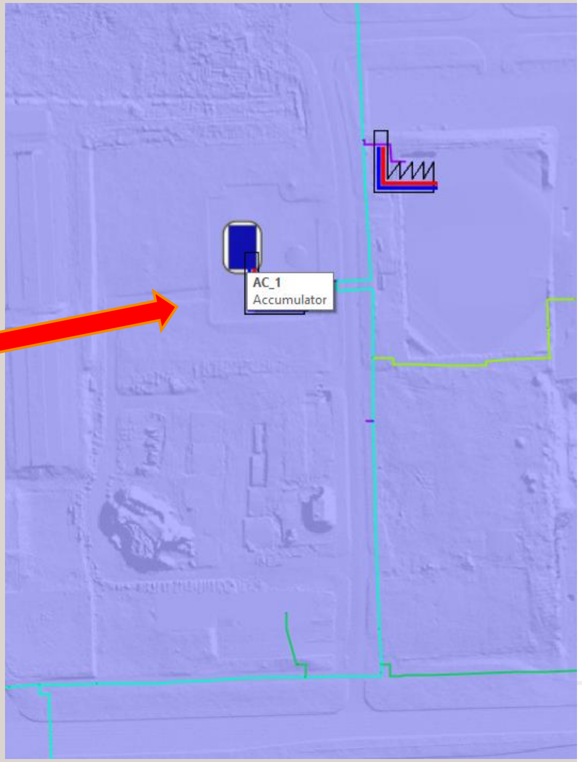
In total this gives 8 scenarios to investigate. The Table 4.1 gives an overview of the number of scenarios.

Table 4.1: Scenarios for 10.000 m^3 tank calculations

Period	Tank discharge	2021+	2030+
Cold winter	15 MW	1	5
Cold winter	20 MW	2	6
Mild winter	20 MW	3	7
Summer	20 MW	4	8

TES alternative locations

Tested using hydraulic model

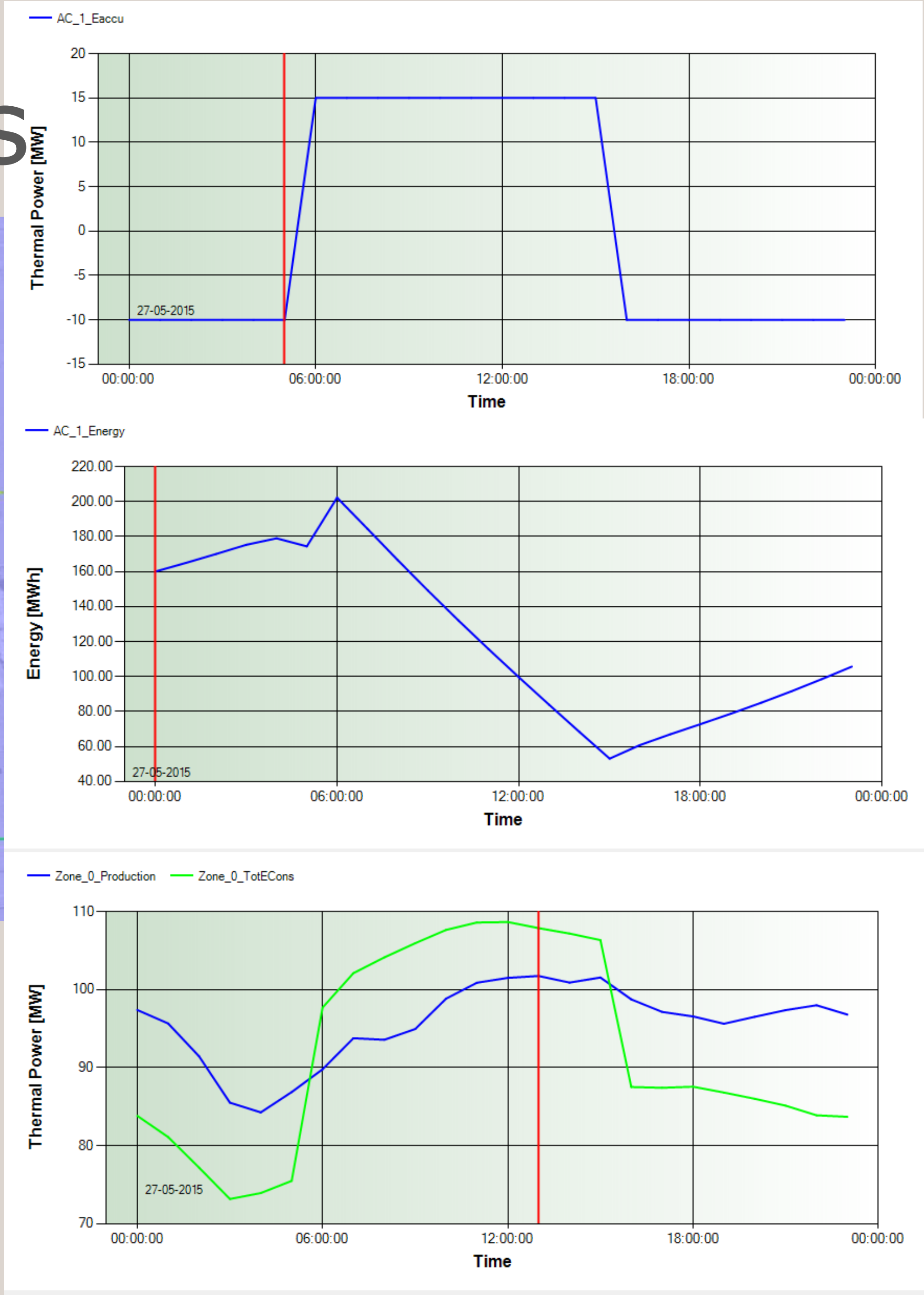


Various locations tested:

- @CHP
- @Anne
- **@Ropka**
- @Tuglase
- @Tulbi
- @Ardla

Still being charged from the CHP

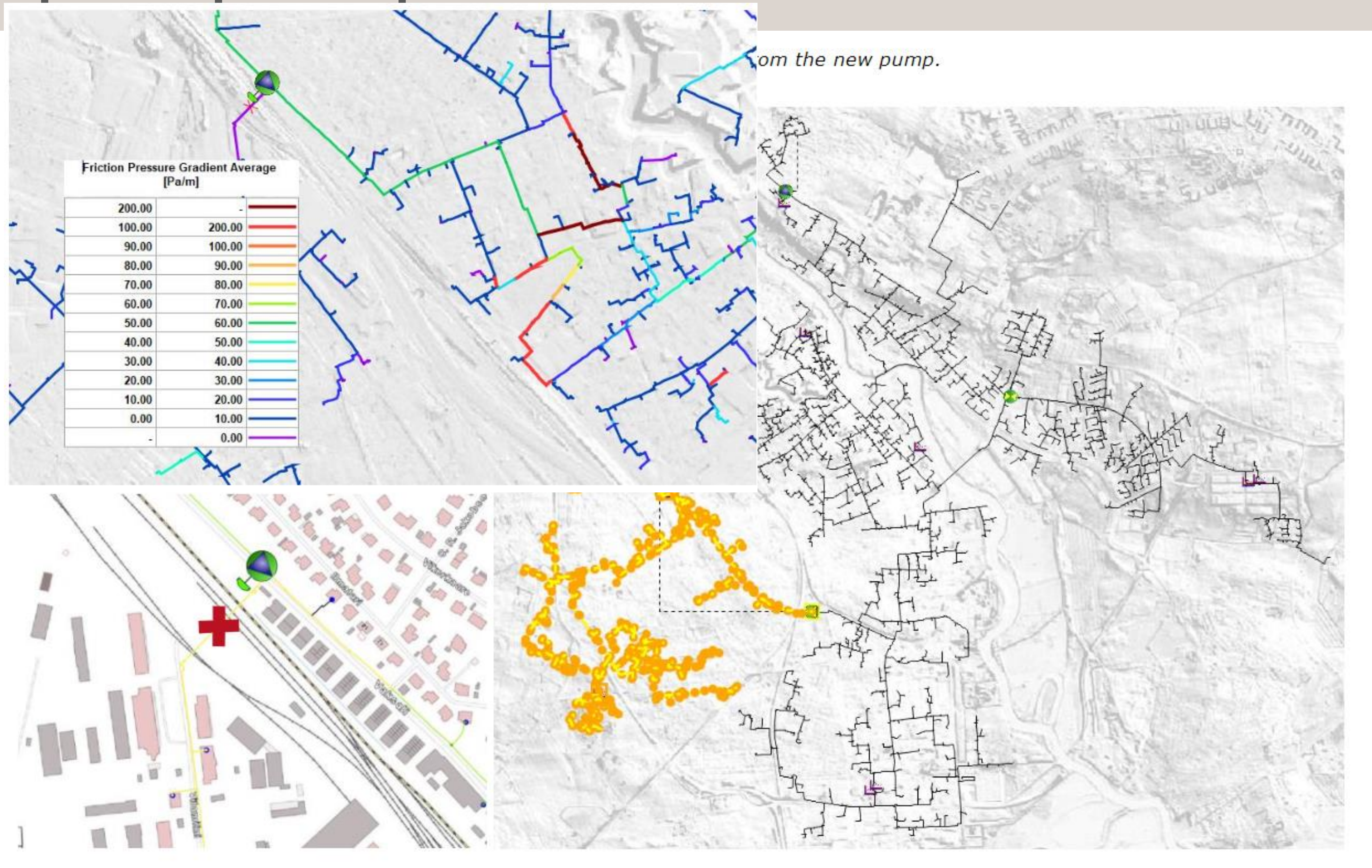
Max 10MW / 34,1 mBtu/h charge and 15MW / 51,2 mBtu/h discharge was found possible at this location.



Booster pump required?

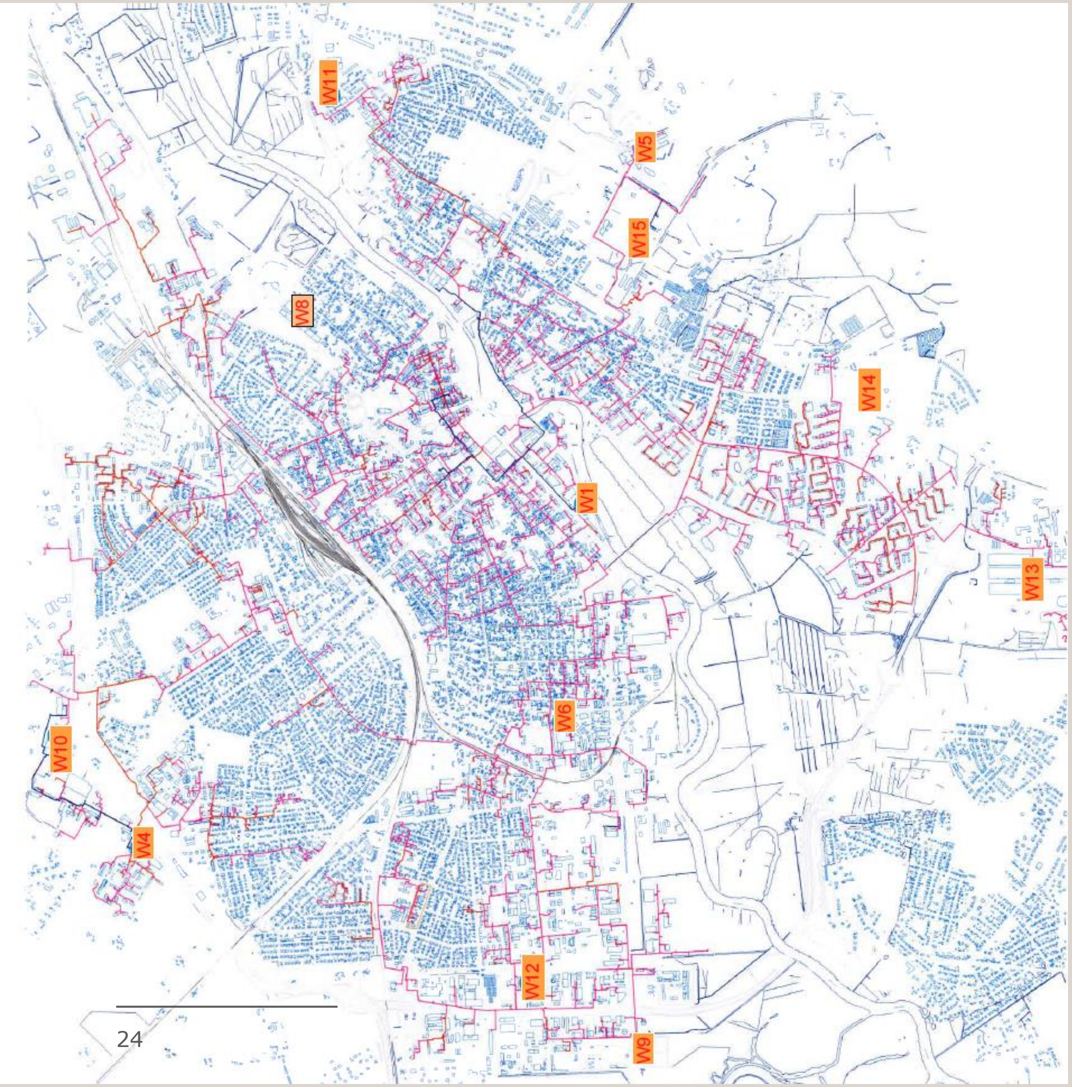
A booster pump was required for the remote TES to be charged by the CHP.

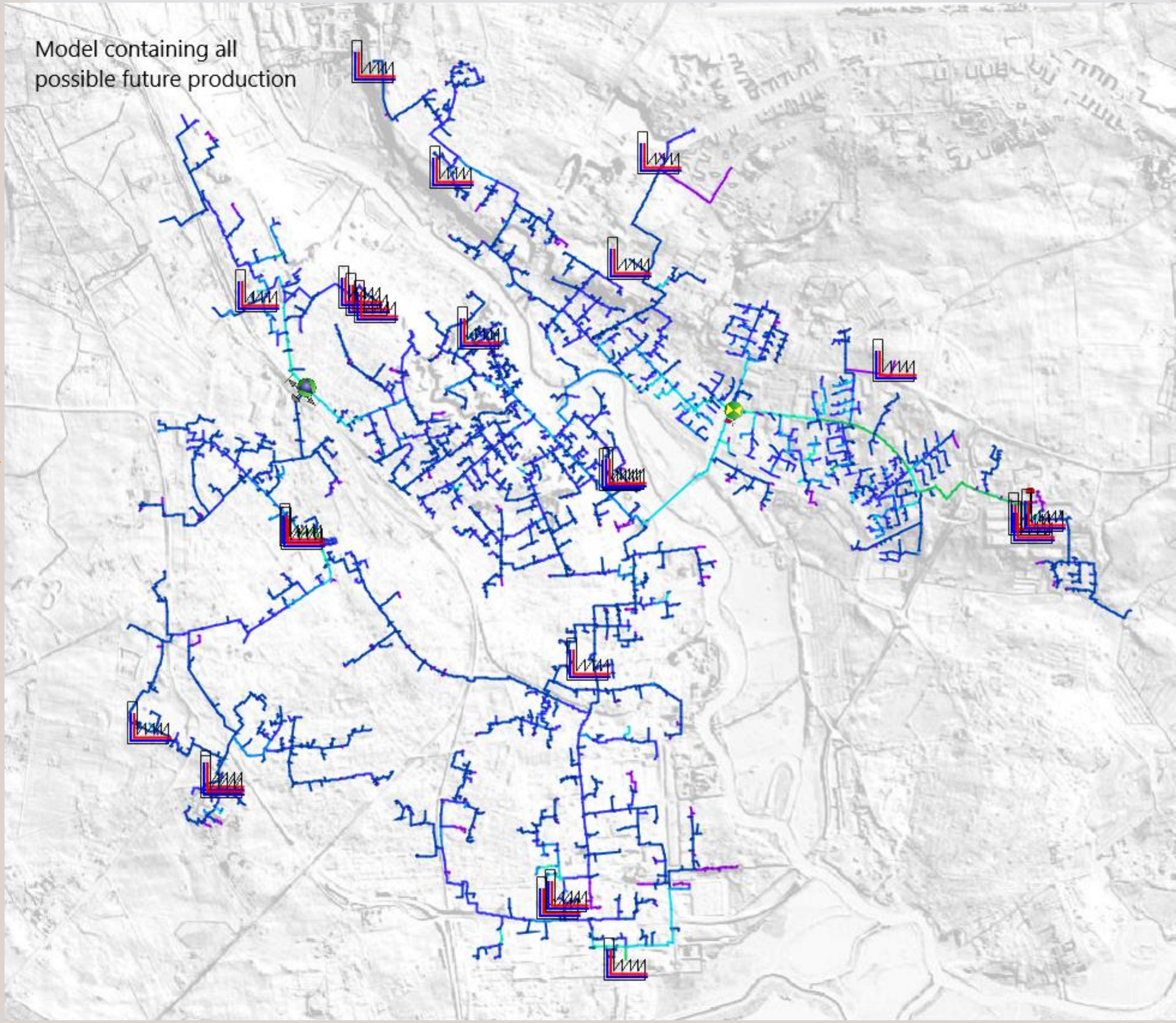
Scenarios were run to determine pump location and necessary valve closures



Waste energy sources

Included in hydraulic scenarios





Waste energy sources

Considerations

Waste heat sources may be cheap, but are they reliable?

Is the energy source constant or is the supply fluctuating or season dependent?

Waste heat may be free, but at what other cost?

Both pumping upgrade, piping upgrade and potential a thermal energy storage may be required to get the free energy. Not to mention regulations. BUT it may be the greenest (and politically correct) thing to do!

		Installed capacity	
Pos	**Name**	**MW_{heat}**	**MW_{cool}**
	Cooling solutions		
W1	Turu cooling plant	1,98	1,4
W2	Turu Possible new HP if feasible		
W3	Tulbi cooling plant	1,4	1
W4	Aardla cooling plant	0,80	0,55
W5	National museum	1,35	0,95
W6	Plastic Factory, comfort cooling	1,54	1,1
W7	Army campus	0,98	0,7
W15	Office		
	Food market/supermarkets		
	New B2B customers		
	Process heat		
W8	Brewery process	1,26	0,9
W8	Brewery comfort		
W8	Brewery sewage from biogas productio	0,00	0
W9	Water treatment plant, Sewage HP	9	
W10	Ice arena	0,44	0,3
W11	Food factory "Salvest"	1,4	1
W12	Kroonpress drying process	0,60	-
W13	Grüne fee Gas engine	4,00	
W14	Crematorium		
	Total	**24,7**	**7,9**

Results

The What-If scenarios indicated a 10.000m^3 /2.64 MGal TES located in proximity to the CHP which also will charge it, is the solution with the shortest payback time.

A larger tank would not be able to be utilized as much due to hydraulic restrictions out of the CHP towards the city.

During winter time the new CHW TES located in the city is converted into a heating TES and will by usage of a new pumping station be charged from the CHP during off peak hours.

A PTES is also possible and a future option, but has a bigger investment and hence a longer payback time.

Waste heat sources are not influencing the TES / PTES operations and will be investigated individually for cost, efficiency and reliability.

Lessons learned

- Hydraulic model for master planning in combination with an energy and cost-benefit planning modelling tool is essential – especially when more production sources are in question to fully exhaust a 360 degrees What-If Scenarios feasibility study.
- For future operation, system optimization and planning a real time energy and hydraulic model (digital twin of the real world) can easily be created using the same tools and be used for optimized planning of operation (cost, pressures and temperatures).
- Several iterations between planning and operation tool is required to determine the most optimal solution – in this case for size, location and utilization of the TES.
- More constraints -> more complex solution, but can be handled with the right tools and good data.
- Thermal Energy Storage is one of the most efficient and flexible ways of peak shaving and utilization of sources not available 24/7 or year round.

Thank you!

Questions?

For further details, please feel free to contact:

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