



WP 3 – ICT Modules and Simulation Tools

Task 3.1 Exergoeconomic optimization tool
for 4th-5th DHC design and operation

**D3.1 Description and report of
exergoeconomic optimization tool for
4th-5th DHC. Preliminary version**



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1 Executive Summary

The goal of HYPERGRYD project is the development of a set of replicable and scalable cost effective technical solutions to allow the integration of Renewable Energy Sources (RES) with different dispatchability and intrinsic variability inside Thermal Grids as well as their link with the Electrical Grids, including the development of innovative key components, in parallel with innovative and integrated ICT services formed by a scalable suite of tools for the proper handling of the increased complexity of the systems from building to Local Energy Community (LEC) levels and beyond, and accelerate the sustainable transformation, planning and modernization of District Heating and Cooling (DHC) towards 4th and 5th generation.

HYPERGRYD also aims at developing real time management of both electrical and thermal energy flows in the coupled energy network complex, including the synergies between them. Therefore, HYPERGRYD aims at three over-arching General Objectives:

- To prove Smart Energy Networks as the future of Efficient Energy Management in DHC in synergy with the Electrical Grids in LEC/Smart Cities of the future;
- To define the roadmap to design and plan future DHC as well as the modernization of the existing ones in different climates and RES penetration levels toward 4th-5th generation,
- To demonstrate HYPERGRYD RES-based Enabling Technologies, Smart Energy Grid Solutions empowered by new ICT tools and services as the key for this evolution.

During the project, the HYPERGRYD's solutions will be implemented across four Live-In-Labs cases in three representative climates, with special consideration to their cost effectiveness and potential replicability to finally achieve these three main objectives.

The purpose of this deliverable in short is to develop tools to reach the highest cost-effectiveness and lowest exergy for the design and operation of future DHC networks. The developed exergoeconomic optimization tool will be based on CAPEX and OPEX as well as technical and environmental boundary conditions.

The target group of this report are DHC planners, optimizers, system operators and software developers.

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2 Introduction

2.1 Scope

The aim of this deliverable is to present the range of functions and the scientific basis of the exergoeconomic optimization tool. The development of the tool runs until month 36, so D3.1 is used to represent the preliminary version of the tool.

2.2 Audience

The target group of this report are DHC planners, optimizers, system operators and software developers. The report provides the target group with information on how the exergoeconomic optimization tool is structured and which functions it already performs or will be able to do. The functions and scientific bases of the calculations are presented. One part deals with the programming of the models and is particularly interesting for developers.

2.3 Definitions / Glossary

Exergoeconomic Optimization Tool - This is a tool that performs thermal calculations of a district heating grid, taking into account the exergy. The exergy level should be optimized in order to avoid unnecessarily high temperatures in the network. In addition, the entire system can be economically optimized through the economic part of the tool. This serves as a decision basis for relevant stakeholders of a DHC system.

QGIS - QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, printing, and analysis of geospatial data.

2.4 Abbreviations

3GDH: third generation of district heating

4GDH: fourth-generation district heating

5GDHC: fifth generation district heating and cooling

ATES: Aquifer Thermal Energy Storage

BIM: Building Information Modeling

CAPEX: Capital Expenses

CHP: Combined Heat and Power

COP: Coefficient of Performance

DHC: District Heating and Cooling

DHN: District Heating Network

DHW: Domestic Hot Water

DSO: Distribution System Operator

DT: PaaS Digital Twin Platform as a Service

GIS: Geographic Information System

HP: Heat Pump

ICT: Information and Communication Technology

KET: Key Enabling Technology

KPI: Key Performance Indicator

LCOE: Levelized Cost of Energy

LEC: Local Energy Community

LIL: Live-in Lab

OPEX: Operational Expenses

P2H: Power to Heat

PV: Photovoltaic

QGIS: Quantum Geographic Information System

RES: Renewable Energy Source

TES: Thermal Energy Storage

3 Scientific Foundations

3.1 4th – 5th generation DHC

Since 2008, fourth-generation district heating (4GDH) has been used as a label or term to indicate a transition route for decarbonization of the district heating industry, and it was further defined in 2014. Several studies on a concept known as fifth generation district heating and cooling have been published in recent years (5GDHC). The research reveals that these two have a lot in common, not only in terms of the overarching goal of decarbonization, but also in terms of the five fundamental talents initially described for 4GDH. The key driving force behind 5GDHC has been a heavy focus on combined heating and cooling, which involves leveraging a collective network near ambient temperature levels as a shared heat source or sink for building-level heat pumps. 5GDHC is discovered to be a promising technology with its own advantages, as well as a complementing technology that can coexist with other 4GDH technologies.

The term ‘generation’, on the other hand, implies a chronological order, therefore the name 5GDHC does not appear to be consistent with the known classifications 1GDH through 4GDH (Lund, et al., 2021).

The evolution of district heating accelerated with a greater focus on energy efficiency, smart integrated energy systems, and the use of locally accessible renewable energy sources, resulting in fourth-generation district heating (4GDH). A temperature level as near to the real temperature requirement of the connected end-users as feasible, at a maximum of 60-70 °C, is one of the aspects of 4GDH. The lower supply temperature reduces DH grid losses and makes the integration of even more waste heat sources, such as surplus heat from data centers and supermarkets, more economically possible than in 3GDH. 4GDH also highlights the expanded usage of heat pumps in DH systems to take use of additional low-temperature waste heat sources or ambient heat sources.

At 4GDH temperatures, both heat pumps and CHP units have better efficiency than at 3GDH temperatures, which is a driving force for increased heat pump capacity. In addition, 4GDH has focused on the synergy of low-temperature DH and high-temperature district cooling (DC) systems for enhancing supply efficiency. A central heat pump with heat and cold storage, similar to an aquifer thermal energy storage (ATES), allows for smart heat pump operation with the option of storing heat in the summer and cold in the winter. Seasonal thermal storage has become a feasible option for long-term storage of seasonally accessible heat sources, as well as a facilitator of a smart and integrated energy system, with the introduction of 4GDH.

Finally, this new generation of DH is well-suited to low-energy structures. Low-temperature demand in low-energy buildings has been found to improve overall system efficiency. As previously stated, the term 5GDHC has recently begun to emerge in scholarly literature. This viewpoint paper examines how this word is used and compares the stated and inferred definitions to the well-known 4GDH definition.

Unlike the previous three generations, 4GDH development entails combining energy supply with energy conservation, therefore addressing the difficulty of delivering heat to more energy-efficient buildings to fulfill space heating and domestic hot water demand. Lower temperature levels enable

reductions in DH grid losses and boosts in the efficiency of heat generating devices as diverse as CHP, heat pumps, and solar collectors, which are all important economic drivers.

Because of the lower temperatures of 4GDH, low-temperature heat sources may supply more heat with less expenditure than prior generations. Lower temperatures can further minimize the requirement for heat pumps by allowing waste heat sources to be directly used through heat exchangers. Another characteristic of 4GDH is the potential for synergy with a DC system at the manufacturing site. By considering adequate supply temperatures and overcoming local differential pressures, current control concepts also allow bidirectional deliveries from local heat sources in 4GDH networks. This is consistent with 5GDHC systems being delivered in both directions. The temperature levels of 4GDH are generally sufficient to meet space heating demands without the need for any temperature boosting at the end-users, such as heat pumps. Low-temperature heat sources are incorporated into the functioning and efficient implementation of smart energy systems in this study.

4GDH also entails strategic and innovative planning, as well as the integration of DH into the operation of smart energy systems, as well as the creation of institutional and organizational frameworks with suitable cost and incentive structures.

4GDH will require the following five skills to be able to fulfill its role in future sustainable energy systems:

1. The capacity to provide low-temperature DH for space heating and domestic hot water to existing, refurbished, and new buildings.
2. The capacity to distribute heat with minimal grid losses in DH networks.
3. The capacity to recycle heat from low-temperature waste sources while also incorporating renewable heat sources like solar and geothermal heat.
4. The capacity to be a member of smart energy systems, assisting in the job of integrating variable renewable energy sources and demonstrating energy conservation in the smart energy system.
5. The capacity to assure appropriate planning, pricing, and incentive structures in connection to operations as well as strategic investments connected to future sustainable energy systems.

The different aspects of the 5GDHC definition are described, and the definitions of 5GDHC are grouped based on the temperature level in which they work. Due to a lack of data in the research described, certain components may be missing. The thermal source location refers to whether the utility company provides heat (central), end-users participate in renewing the heat network (distributed), or the system may balance itself exclusively utilizing heating or cooling from prosumers. The capacity of a system to function at stable or variable temperatures is referred to as the system temperature. The two-pipe network is the most typical feature.

This system employs both cold and warm water pipelines, which, when combined with a heat pump installed at the end-user, guarantees that the proper temperature is maintained. The one-pipe network works similarly, but it relies on only one ambient temperature loop to provide the necessary

thermal energy for both cooling and heating in the homes. The majority of networks were designed to operate at temperatures below 30 degrees Celsius, with a handful running at ground level or between 30 and 50 degrees Celsius.

When compared to the previous definition of 4GDH, 5GDHC is characterized primarily by the use of temperature adjustment at the end-user level to reach the appropriate operational temperatures at the building level, as well as optionally insulated pipes. Heat pumps may be used as producing units in the 4GDH DH system. In several 4GDH research, heat pumps installed at the end-user are mentioned as a way to improve temperature levels and obtain adequate household hot water temperatures.

According to our opinion, 5GDHC's primary themes are:

1. Capitalize on the synergy of combined heating and cooling in areas of mixed-use buildings.
2. Reduce the barrier to utilizing local waste heat sources and reduce upfront investment costs for the utility company, though the required initial investment at the end-users will be higher.
3. Enable less restrictive organic growth of the system, as central heat supply is not as critical, because new additional end-users will both add and use heat from the net.

The five skills specified for 4GDH systems can be recognized as typical abilities for 5GDHC systems, with some extra concerns. The second capability, lowering grid losses, is easily attained. On the other hand, with a heavy emphasis on local harmonisation of combined heating and cooling in 5GDHC systems, it may be difficult to completely apply the fourth ability of integrating with a smart energy system (Lund, et al., 2021).

3.2 Basics of the exergetic approach

The objective of this developed tool is to reduce both energy and temperatures in general to improve access to renewable energy.

The energy consists of the exergy and the anergy. Exergy is the fraction of the total energy that can do work and be converted into any other form of energy. Anergy, on the other hand, is the part that cannot do any work (Steinmüller, Tichler, Kienberger, & Lehner, 2016). It is therefore favourable in a process, e.g. in the case of heat transport, if the proportion of the exergy of this process is as high as possible and as little heat as possible is lost.

With the help of the exergy analysis, exergy losses in a process can be located and quantified. With heat, only that part of the energy that is above the ambient temperature T_U is exergy E_T , the other part is anergy. The proportion of exergy depends on the temperature of the supplied heat T and is equivalent to the Carnot efficiency. It therefore corresponds to the maximum work that can be done by a heat flow in a reversible heat engine. The proportion of exergy is calculated as described in the equation below. The energy is multiplied by the Carnot factor (Lund, et al., 2021).

$$E_T = E_n * \frac{T - T_U}{T}$$

Equation 1. Proportion of exergy

This exergy-based approach provides a better understanding of the quality of the energy flows and can thus contribute to more effective measures to save energy sources and protect the climate. Fossil fuels with a high exergy content are used worldwide to satisfy this low exergy requirement. It is therefore obvious that the spread of LowEx systems and the exergy concept can contribute to a faster and more effective transition to a sustainable energy system.

The use of suitable energy carriers for the respective applications (namely with regard to the required exergy or temperature level) can lead to a drastic increase in exergetic efficiency and thus in exergy and energy consumption as well as the associated greenhouse gas emissions. All types of heating that work with flame temperatures of 700 °C and more to generate a room temperature of 21 °C do not fit into a LowEx strategy. This applies in particular to gas heaters, but also to hydrogen or biomass heaters (Kranzl, Müller, & Matzenberger, 2012).

In order to integrate more renewable energies into the energy system, the system needs a certain flexibility, since the generation peaks of renewable feed-in usually do not occur at the same time as the load peaks. There are certain flexibility options for this.

Transmission and distribution options are: (Kienberger & Lukas, 2018)

- network expansion in the transmission and distribution network to eliminate network bottlenecks,
- the network conversion adapted to the intelligent supply system (e.g. installation of controllable local network transformers),
- the improvement of voltage stability (e.g. through reactive power management),
- a European balancing in the interconnected grid,
- the expansion of storage options and
- the hybridization of the energy system (power-to-X technologies, CHP)

The exergy factor ε describes the proportion of fuel energy that can be converted into work with reversible oxidation in a real environment, shown in the equation below:

$$\varepsilon = \frac{\text{Exergy}}{\text{Energy}} = \frac{B}{E}$$

Equation 2. Exergy factor (Kienberger & Lukas, 2018)

The exergy factor is necessary for further calculations with the various optimization techniques.

The exergy factor for electrical energy in the model is 1. For chemical energy in natural gas, the exergy factor can be greater than one, depending on the system boundaries. The factor 1 is assumed here. For the determination of an exergy factor for the provision of heat from the DH network, it can be assumed for simplification that heat is supplied or returned at a constant flow and return

temperature independently of the outside temperature. This means that the temperature of the heat transfer medium does not change from the heat input to the consumer or vice versa (Kienberger & Lukas, 2018).

Exergy-based analyses are very convenient methods for assessing the performance of energy conversion systems (Tsatsaronis, 2007). Available approaches for exergy analysis typically consider exergy, exergo-economic/thermo-economic, which combines economic constraints with exergy analysis to give the information that cannot be gained by energetic and economic evaluations (Tsatsaronis, 2007), and exergo-environmental, which includes exergy and life cycle analyses⁸. Several methods can be found in the literature for exergo-economic analysis, whose full references are given in (Cárdenas, García, Romeral, & Urresty, 2009). So far, however, existing exergy modelling tools do not provide any information about how one component affects one another, especially those components that use mostly waste energy. This lack of information can be addressed through advanced exergy-based methods (Tsatsaronis, 2007) (e.g. ADLOWEX and ALEXERGO, (Açikkalp, Tahsin Yucer, Hepbasli, & Himet Karakoc, 2015)).

4 Description of the Exergoeconomic optimization tool

4.1 Planned range of functions

The Exergoeconomic Optimization Tool should have a wide range of calculation and optimization functions. The main functions can be found in Task description 3.1. The project team has summarized the most important functions of the tool in Figure 1. Basically, the tool is based on QGIS, supplemented by Python scripts.

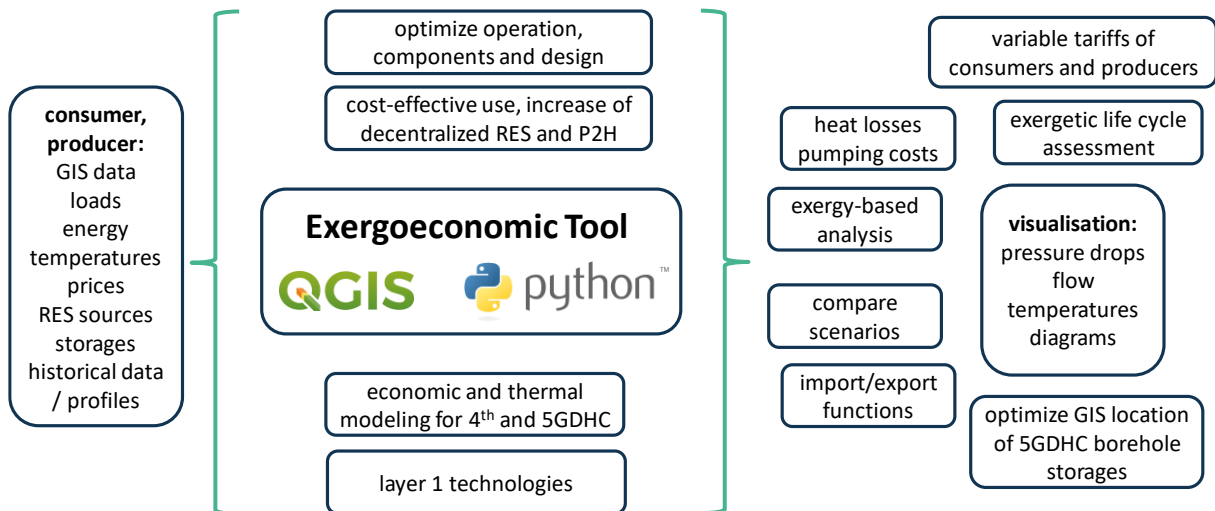


Figure 1: Overview of the planned range of functions of the Exergoeconomic Optimization Tool

4.1.1 Input data from consumers and producers

It can be seen that some input data from consumers and producers are necessary for the calculations, e.g. loads, energy, temperatures and prices. The tool is intended to plan and optimize the system and therefore only accesses historical data. Real-time data is therefore not required.

Furthermore, the GIS data of the existing district heating grid must also be available or inserted as part of the tool. The DH grid should either be loaded into the program as an existing GIS file or drawn in the tool itself, for example for new pipes.

Characteristic curves or profiles should be created for consumers for which historical measurement data is missing in whole or in part, which depict the consumer and thus make calculation possible.

4.1.2 Functions of the tool

The main functions of the Exergoeconomic Optimization Tool include the optimization of the operation of the DH system, as well as the design of components, e.g. to find optimal pipe diameters in relation to the overall system. Other components should be able to be optimized through parameter variations. This will make it possible to plan components in a way that makes economic and technical sense. This is to avoid oversizing.

The optimization of the operation will be particularly important, since on the one hand problems with existing DH systems can be identified (e.g. excessive flow rates from consumers, too high temperature levels, unused storage resources, ...) and on the other hand suggestions for improvement can be drawn up. The tool can thus be seen as decision support.

In addition to the optimization of components, the cost-effective use of the overall system or individual subsystems is also important. Here, a cost reduction should be achieved through a technical and economic comparison, for example through the use planning of heat generators. Parameter variations should show the most sensitive points of the overall system and thus serve as a basis for decision-making.

The calculations and comparisons should make it possible to increase the use of renewable energy, especially in decentralized locations. This could be possible, for example, through decentralized waste heat feeders or through P2H systems (e.g. heat pumps). The tool from the partner GridSingularity is to be used to use available excess electricity from a local energy community for P2H applications.

The calculations of the DH grid are based on thermal and economic functions, which are described in more detail in Chapter 4.2. In addition, it should be possible to include some Layer 1 technologies from Workpackage 2 in the calculations, such as the steam engine from Ranotor. Here, the amount of electricity and heat produced is taken into account in operational planning and economic efficiency.

In order to do justice to the market situation and to be able to present future developments better, it should be possible to store variable tariffs (especially heat) from heat consumers and heat generators. As a result, the planning of heat production can also be economically optimized and peak loads can be reduced. As an incentive system for consumers with higher return temperatures, a bonus could be calculated here in order to make a statement about what effect the reduction of the return temperature would have and what the economic effect would be.

When optimizing operation, the focus is usually also on the electrical consumption of the pump. The pumping costs should be able to be displayed and savings potentials should be shown. It will also be possible to compare overall economics, for example to show the effect of smaller pipe diameters (lower investment costs) with the higher pumping costs.

Decentralized heat generators should preferably be considered with a return-return feed-in or flow-flow feed-in. This reduces strong fluctuations in the differential pressures in the grid.

With the heat generators, there should also be the possibility to define further framework conditions, for example times when a boiler is not in operation (e.g. in summer), or a boiler must be operated to keep up embers with approx. 5% heat output. The tool will also enable the optimization of operation or individual components, e.g. statistical evaluation of how many hours a pump is used and how much, or boiler outputs and hours per year below 30%.

For the exergetic optimization of the DH system, the temperatures required by the consumers are analyzed, from which the flow temperature for the grid is specified. This should also provide

information for the historical data as to what effect a lower flow temperature would have had over the course of the year. Exergetic indicators should be defined for the evaluation, to analyze the exergetic operating modes and to optimize them based on this. This makes it possible, for example, to evaluate decentralized heat producers and also to provide appropriate tariffs depending on the temperature level provided.

The calculations of profitability should take into account the investment costs, consumption-related costs and operational costs. Here, through parameter variations and different use cases, an economically optimal operation and cost savings can be achieved. It should also be possible to show the differences between the individual scenarios.

4.1.3 Presentation of the results

In order to visually direct the focus to parts of the network, there will be a colored representation in the visualization of the network. Here, for example, the pressure losses of the pipes can be shown in color (see also chapter 4.2.3), or the flow, or the temperatures. It should be possible to show heat losses from the pipes.

In addition, the GIS location of heat storages (e.g. borehole storages for 5GDHC) should also be optimized and displayed. However, the placement of the heat storages would have to be done manually in the program, since factors such as the availability of plots of land have to be taken into account.

Export functions will be available to continue calculating with the results in other analysis tools, GIS or BIM applications. Furthermore, graphics and pie charts, as well as KPIs, will represent the technically and economically optimal case.

4.1.4 Integration to the HYPERGRYD platform

The HYPERGRYD platform represents the common unit of the tools created in Workpackage 3. The platform will be available as "Platform as a Service" (PaaS). The exergoeconomic optimization tool will be integrated via an API interface (Figure 2). It will be possible to visualize the results and diagrams on the platform. Different scenarios should be able to be compared here. Access to the platform should be possible for different users, such as planners, DH grid utilities, decentralized heat generators, or the consumers themselves. The Exergoeconomic Optimization Tool itself is operated by the GET project team, as it requires the appropriate know-how and thus avoids user errors.

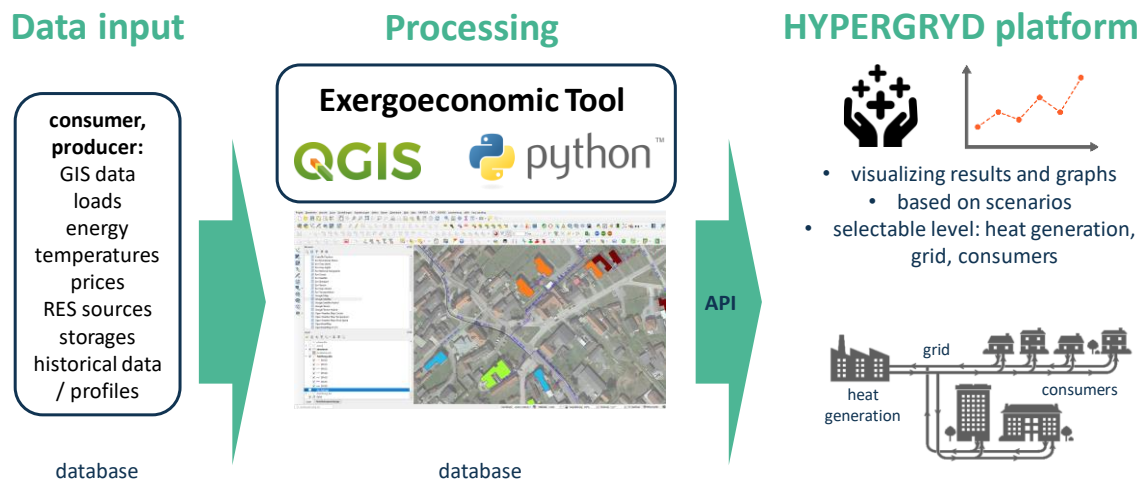


Figure 2. Integration of the Exergoeconomic Optimization Tool to the HYPERGRYD platform

The platform's district heating grid should be able to be taken over by the tool. It is also planned that individual pipelines can be drawn into the platform, for example for customer extensions. The user should be able to make some changes, e.g. of framework conditions, in the platform, which then serve as input for the tool.

4.2 Description of the current range of functions

The following description includes the development status of the Exergoeconomic Optimization Tool for this report as a preliminary version of this tool. Therefore, some of the functions described in Chapter 4.1 have not yet been implemented and will be worked out before deliverable 3.2 is completed.

There exists a lot of tools for optimizing and simulating a grid. The problem with these tools are, that you need in a special format (grid as graph with edges and nodes), where almost no grid operator can provide, or you need to draw the whole grid in this simulating tool, which took a lot of time and can't be used for other tools. Our approach is based on information which already exists.

The Exergoeconomic Optimization Tool is realized as plugin in the open source tool QGIS (Figure 3). QGIS is a tool which can handle a huge variety of input formats including GeoJSON, GeoPackage and GML. The most interesting function is the possibility to import AutoCAD plans. Most of the district heating operators have their grid plans available as AutoCAD plans, which are hardly used due to the high license fees and cannot be used by external programs. The plugin DXF Import / Convert reads all Layer in the AutoCAD-plan and imports all objects with all accessible information to QGIS.

Equally common is the use of csv / xlsx lists to store additional information on pipelines and consumers. QGIS can also read these lists and save them as layers without geometry. The assignment of the list entries to the customers is always problematic. IDs are not updated without automatic

management, which is not possible in Excel, and the IDs are written in different ways or are not set everywhere when changes are made, which means that IDs set manually become unusable sooner or later. The customer name is for many operators the most important feature to identify the customers. But even here, people change, spellings are not unique and errors occur in the designation. With the build in function “Nominatim-Sammelgeokodierung” it is possible to generate a point layer where the information from the csv is stored in a georeferenced point.

All the Objects in QGIS can be accessed and modified by its build in python interpreter (PyGIS). This python interpreter is a unmodified python installation connected to QGIS and can use all packages available for python. The interpreter can be accessed from QGIS directly and code can be written to the interpreter or a file can be read. A second way is to develop a plugin for QGIS, so the code can be run by clicking on an icon and a GUI can be used.

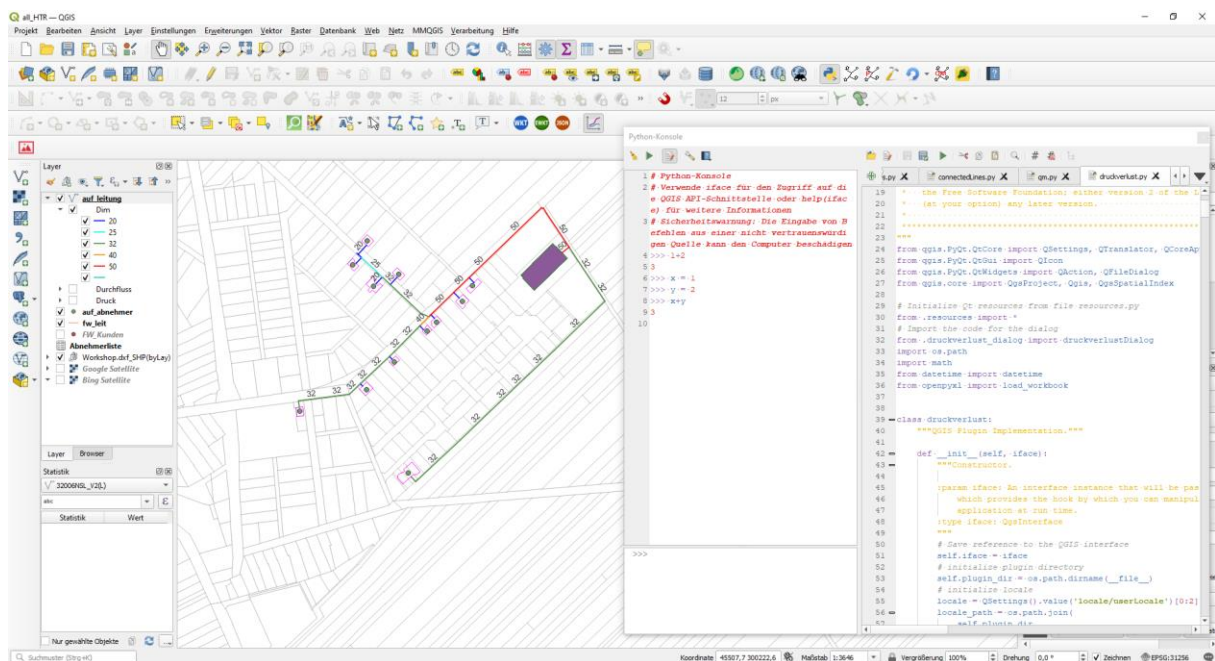


Figure 3. User interface and python interpreter at QGIS

4.2.1 Structure

The programme code is separated in different classes in one package. The most important classes are:

- pipeset consisting of pipe where the information about the installed pipelines are installed. Especially the information about dimension, diameter and thermal conductivity are stored in this class.
- the calculate class where physical calculations can be called collectively

- the class singleline where all information concerning the individual pipe including the type of pipe used (class pipe) is stored.
- the Customer class, where information about the individual customer, such as contractual connected load, current output, temperatures and installed transfer stations are stored.
- the classes edges and nodes, where the actual plan is being translated for external tools.
- the class FWnetwork, which consists of the lines, the customers and some functions.
- the classes Simulation and Calculation where Calculation stores the results of the calculation for a given timestamp and Simulation stores a list of calculations for the given time period.

The first step for the calculation is to create a new object from the FWnetwork class and pass the name of the layer for the grid. The given layer is searched for items with valis geometry and all founded items are added to the FWnetwork object as a singleline object. Also the IDs of the items are stored in an index for faster searching and a spartial index is build up with this items for getting the distances between two objects very fast. After this a standard pipeset is generated if no existing pipeset is given.

Then the function set_all_connected gets for all generated singlelines the first and the last point of the line and gets with the spartial index the next 10 neighbours. The amount of neighbours is a variable of the FWnetwork-class and can be modified. The same for the maximum distance between the neighbours. This function unfortunately does not work reliably, so the distance between the endpoints and the neighbours are calculated again and if the distance is higher than the given accuracy, the neighbor is discarded. The results of the neighbor detection is stored in the singleline-objects (Figure 4).

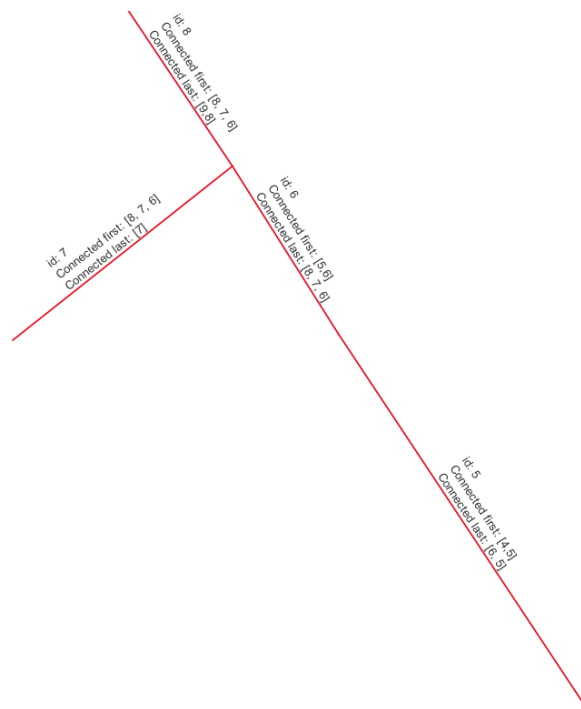


Figure 4. Description of the IDs and connection

A lot of tools needs nodes and edges to work. Edges are basically the singleline objects, but the nodes need to be generated. For all singlelines in the network the before detected neighbors are readed and is stored in an index. If there is no entry in the index a new node is generated with the coordinates from the according endpoint and the neighbours are set. If there is an entry already in the index, what arises when the same point is tested from one of the neighbors, nothing is done. After this the nodeIDs are set in the singlelines (Figure 5).

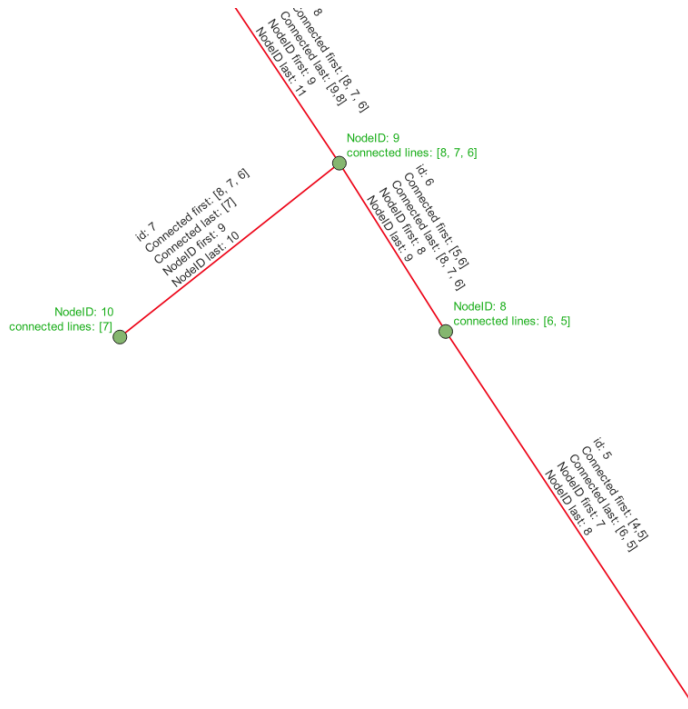


Figure 5. NodeIDs and connected lines

The next step is to add the customer layer to the FWnetwork. Analogous to the grid layer there is a check if a geometry exists and is valid and if so the geometry and the connection power is stored as object customer in the FWnetwork. The spatial index is used to get the nearest line, which ID is stored in the customer too. The geometry can be a single point or a polygon (Figure 6).

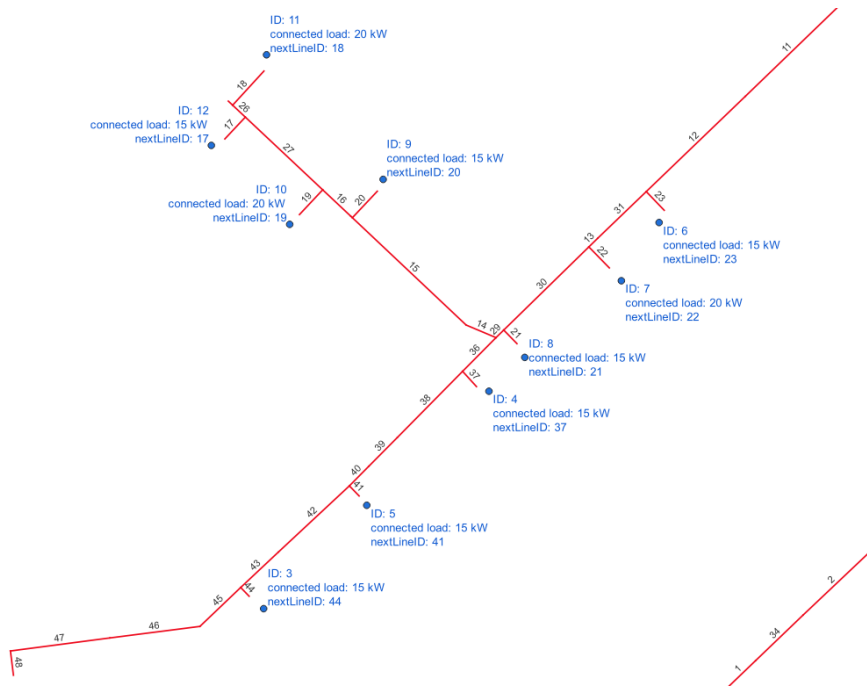


Figure 6. Geometry, with single- and polygon lines

Now all necessary data is prepared. The next step is to set for all lines a predecessor and successors (Figure 7). Starting from a given line a minimum spanning tree is created where each line has exactly one predecessor. All the other connected lines are successors. Predecessor -1 means that no predecessor was found. On the one hand, this can be due to the fact that there is no predecessor, since it is the first line after the boiler, or that this line cannot be reached from the starting point.

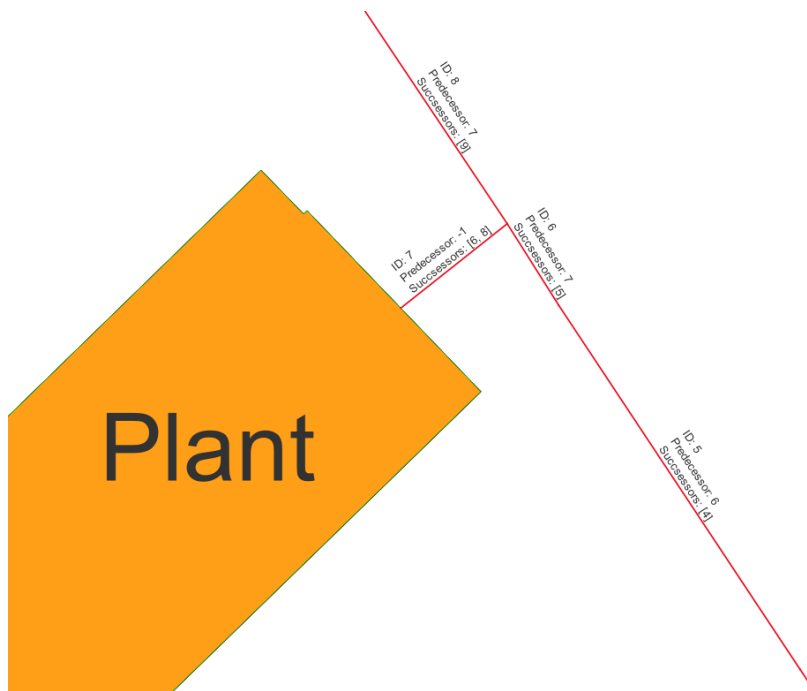


Figure 7. Definition of predecessor and successors

Next, the flow is set. For this purpose, the required flow for every customer is calculated with the required load and the flow and return temperatures, which are assumed to be e.g. 80/50 if no other values are specified. The calculated flow of each customer is added to the singleline connected to the customer and all predecessors. So the flow in the whole grid is calculated (Figure 8).

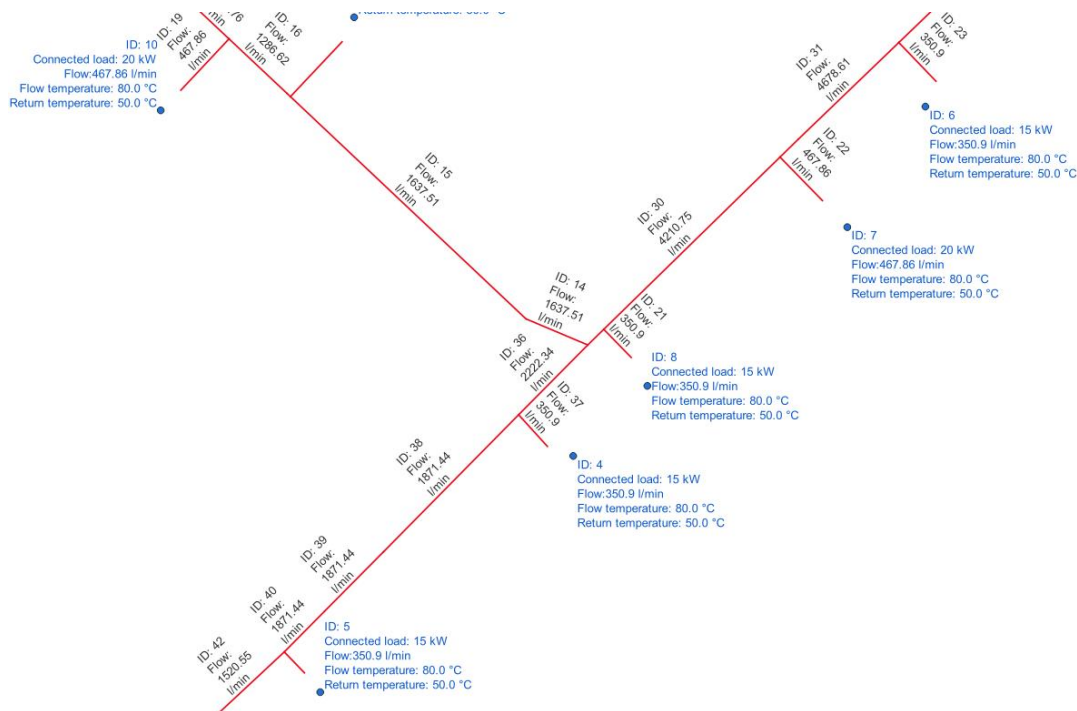


Figure 8. Flow of the pipes are calculated

The pressure loss is then calculated with the flow rate and the properties of the installed pipe. With this information, the specific pressure loss for each individual pipe section can be calculated and with the length of the section, the pressure loss of the entire section is calculated. To calculate the pressure loss of the entire grid, the losses of the individual parts are summed up, starting from the heating plant (Figure 9).

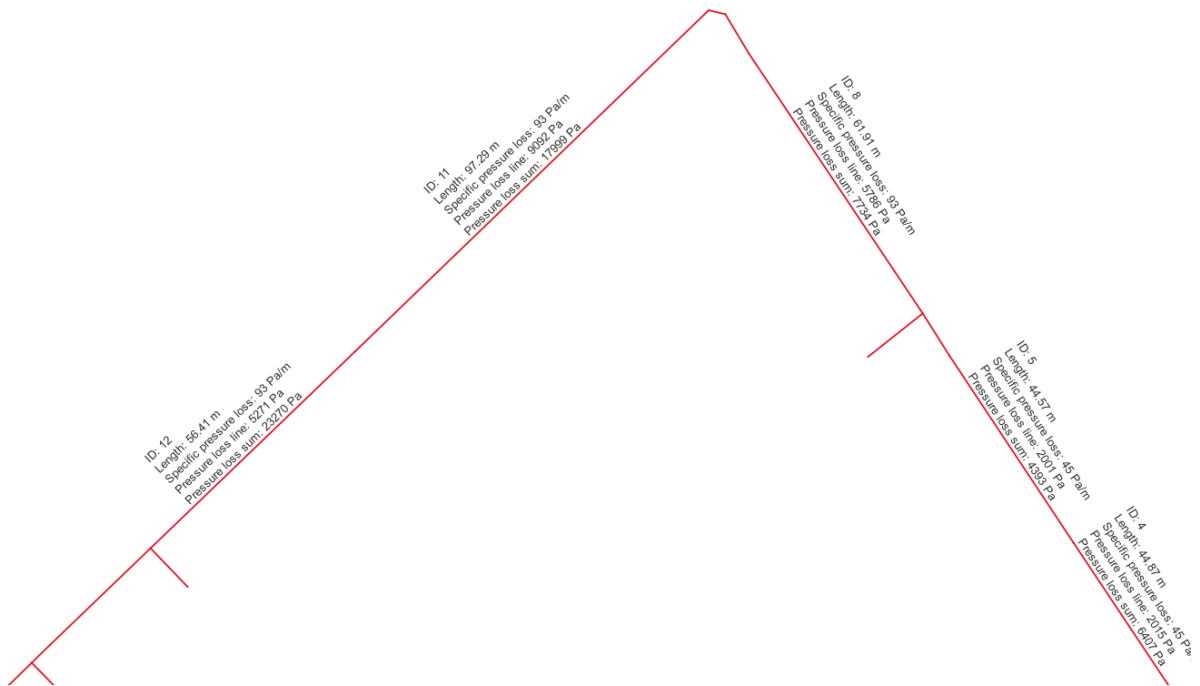


Figure 9. Pressure loss of the pipes

If the type and dimension of the installed lines is not known, an automatic dimensioning of the grid can be made (Figure 10). For this purpose, the specific pressure loss is calculated starting with the smallest available dimension. If the calculated value exceeds a threshold value, the next larger dimension is used for the pipe. This is done for all pipes in the network and as a result the pipe network is saved with all determined dimensions. This is especially useful for new district heating networks to be built, but it is also very interesting to make a comparison of the real installed dimensions and the ideal dimensions. In this way, the user can quickly see how much the network has changed due to new connections and terminations and where there is still unused potential.

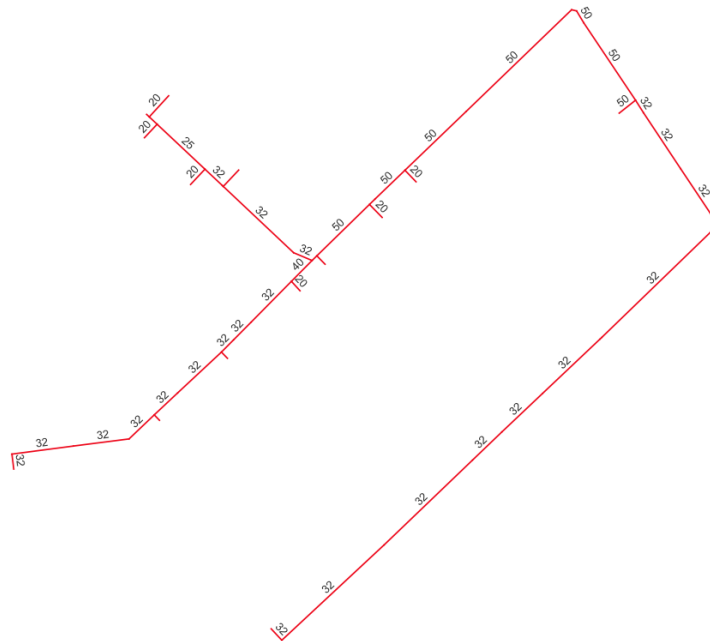


Figure 10. Calculated dimensions of the grid

After the calculation, the results for a simple time point are saved as a separate layer. One layer is saved for the grid lines, one layer for the nodes and one layer for the customers. The geometric properties of the original layer as well as the most important calculated properties are saved in these layers. These new layers can be used in QGIS for visualization, export or further calculations (Figure 11).

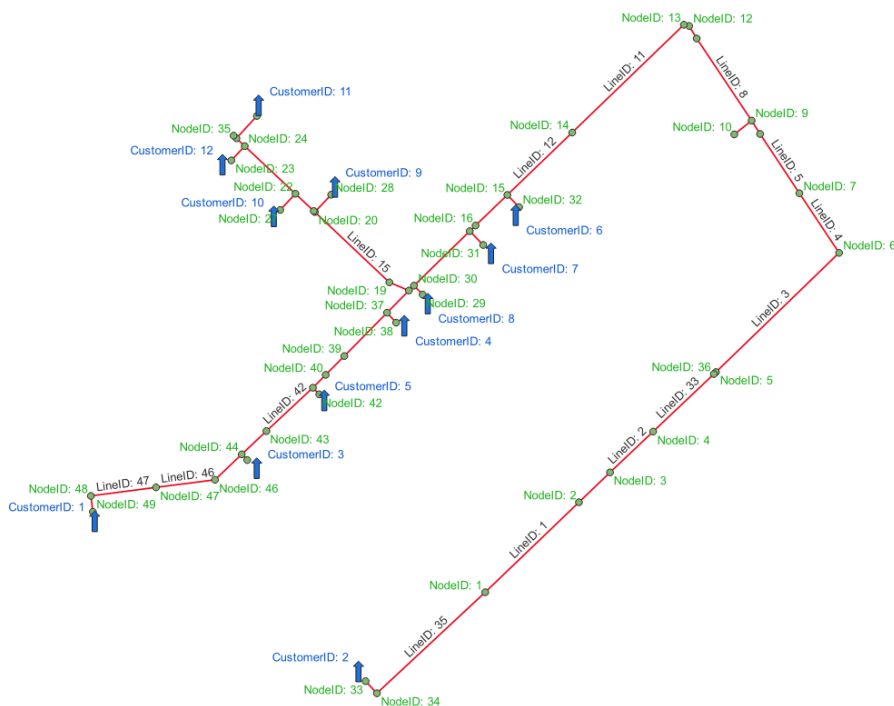


Figure 11. Different layers for visualisation

4.2.2 Mathematical functions

Some of the required mathematical functions of the tool are presented below.

For calculating the pressure loss a function is used, which needs temperature, flow, pipe outer diameter, pipe wall thickness and pipe roughness as parameter. With these values different parameters are used.

The density of the water is calculated with an approximation formula depending on the temperature. The formula is:

$$0.0000101958 * \text{temperature}^3 - 0.0048944768 * \text{temperature}^2 - 0.0373335634 * \text{temperature} + 1001.0589917397$$

Equation 3. Equation of the density of the water

The constants are determined experimentally.

The kinematic viscosity is calculated by eta/density of water, where eta is calculated analogous to density with the formula:

$$0.0000000014 * \text{temperature}^4 - 0.000000004606 * \text{temperature}^3 + 0.000000613585 * \text{temperature}^2 - 0.000042925552 * \text{temperature} + 0.001646878432$$

Equation 4. Equation of the kinematic viscosity of the water

Both formulas are only approximate values, but they are sufficiently accurate in the relevant temperature range between 20 °C and 150 °C.

Parameters like inner diameter of the pipe, area of the pipe, velocity in the pipe or the Reynolds number are calculations which are determined with the help of the already calculated values.

The last required parameter is the pipe friction coefficient. It is determined in several iteration steps where a single iteration step is calculated with the following formula:

$$\left(\frac{1}{-2 * \ln \left(\frac{\text{pipe roughness}}{\text{pipe inner diameter}^{3,71}} \right) + \frac{2,51}{\text{reynolds number} * \frac{\text{pipe friction coefficient}^2}{\ln(10)}}} \right)^2$$

Equation 5. Equation of the pipe friction coefficient

This calculation is iterated 6 times, since the accuracy increases only minimally with more iterations.

The pressure drop is then calculated by:

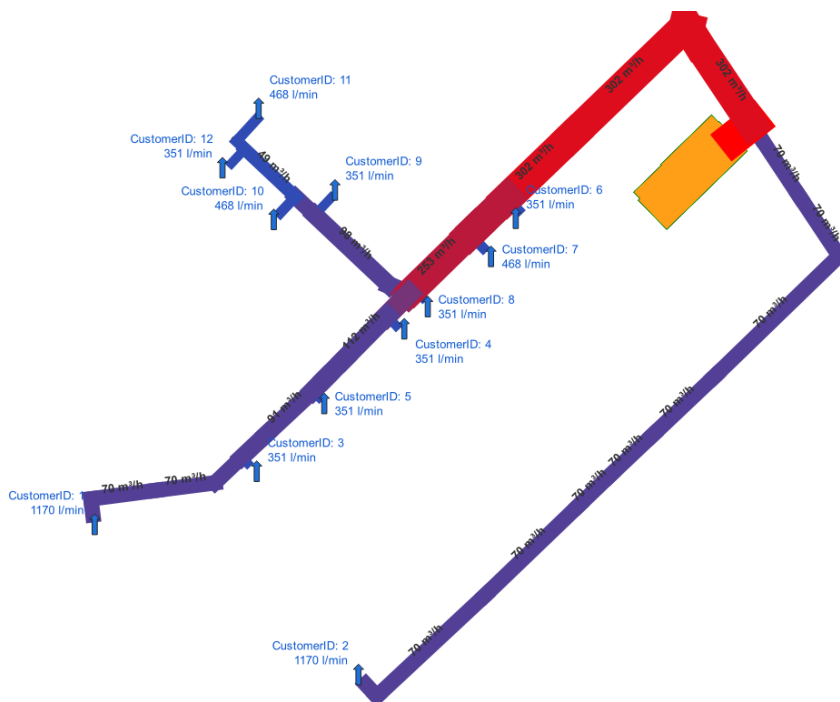
$$\text{pipe friction coefficient} * \frac{1}{\text{pipe inner diameter}} * \frac{\text{density water}}{2 * \text{velocity in pipe}^2}$$

Equation 6. Equation of the pressure drop of the DH pipes

This value is valid for a Reynolds number > 2320 . For smaller values Reynolds number divided by 64 is used.

4.2.3 Presentation of results

One of the best features of QGIS is the ability to flexibly display georeferenced information. The information stored in the individual objects can be used for visualization. As an example, the flow rate of the network was used for the line thickness of the pipes (Figure 12).



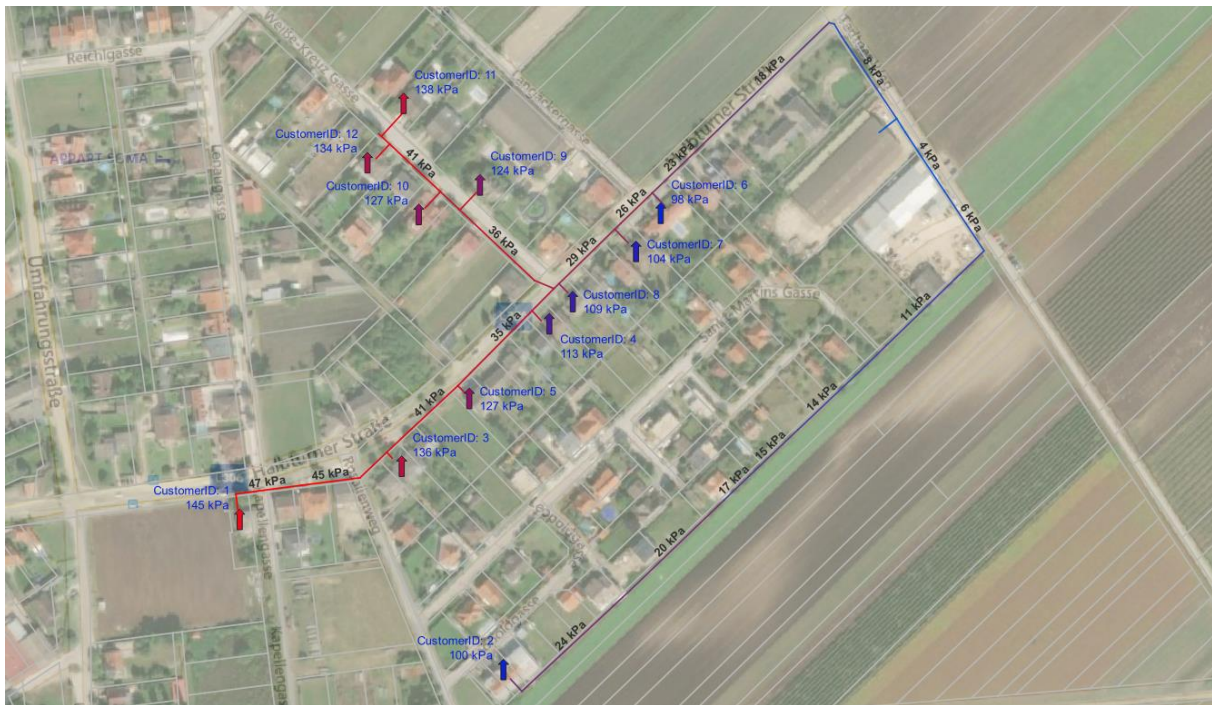


Figure 13. Different layers and maps are available in QGIS for visualisation

4.3 Description of the further steps and range of functions

The basic range of functions has already been described in Chapter 4.1. In concrete terms, this means that the first technical calculations, visualizations and export of the results are possible with the tool. The next steps are to refine the calculations in the area of exergy analysis on the one hand and in the area of profitability calculation on the other. The individual scenarios can then be evaluated and optimized in detail, exergetically and economically. Coordination with the other project partners continues in order to further develop the tool.

5 Conclusions

The report showed the basic requirements for the Exergoeconomic Optimization Tool and which calculations are currently possible. The details needed to implement the tool, such as importing the DH grid, were listed. A few new implementation steps were shown here in order to be flexible when importing the raw kPa data. The possibilities of visualization were also shown, such as the color design of the flows or pressure losses. At the end, the next steps that are necessary for the further implementation of the tool were listed. A detailed report on all implemented functions is given in D3.2, at the end of this task.

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