



District cooling planning tool framework and specification

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Executive Summary

Work package WP5 “Planning tool” provides means for evaluating the performance, benefits and potential of a District Cooling (DC) system. The aim is to create an easy-to-use open-source tool that enables analysis of a cooling system in defined area with a group of buildings connected.

Most of the development of the planning tool takes place within WP5 but the implementation will be carried out in parallel with WP3 and WP4, including information exchange and possible interaction between the WPs.

The calculation will be carried out for a representative full year of operation. The results will be further used as input for a Life Cycle Analysis (LCA) to obtain both economic and climate impact analysis for the system. At this stage the structure of the tool is designed with input and output parameters defined.

The tool is aimed to be easily configurable by providing the user possibility to try out and compare effects of different assumptions on component specifications, costs and other input data. Feasibility of a DC system may be studied, and comparisons to building and/or space specific cooling systems can be made, presenting the benefit of DC.

In its current stage the Deliverable D5.1:

- describes the investigated systems in detail, setting the boundaries and scope for the analysis to be carried out by the tool
- introduces the methods used for energy, economic and environmental analysis
- lists and describes the input data requirements set by the system definition
- presents the subsequent program implementation.

The envisaged main input parameters for the tool are cooling load, distribution network characteristics and available resources for production. The tool will also be used to find out a reasonable size for storage solution based on the availability of resources and variation of demand during operation. Cooling load can either be set manually if e.g. measurement or simulation data is available, or evaluated e.g. according to floor area, type and geographic location of the consumer and a pre-defined load profile.

An environmental analysis component for the planning tool has been worked out. It enables assessing the GHG emissions of the studied cooling system. It will also allow for comparing the emission impacts of planned DC systems with the reference system.

The data collecting for the LCA study was carried out from literature and from LCA databases. As the planning tool will be an open access tool, also the LCA data and data sources will be openly reported. However, it was recognized that in some cases no suitable data is available outside the commercial LCA databases, therefore a need will arise to offer in the tool only aggregated data. In this context, for example the emission data per technical component unit will be shown rather than per raw materials used.

Programme structure, data storage solutions and GUI design are considered at this stage but will be duly addressed in the reporting of implementation phase (D5.2).

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Nomenclature

DC	District Cooling
WP	Work Package
DoW	Description of Work
KPI	Key Performance Indicator
PV	Photovoltaic
GUI	Graphical user interface
LCA	Life cycle assessment
GHG	Greenhouse gas
NPV	Net present value

1 Introduction

INDIGO project focuses on supporting the development of more efficient, intelligent and economic district cooling (DC) systems by improving system planning, control and management.

As a part of meeting these goals, an open-source stand-alone planning tool for evaluating the performance, benefits and potential of a DC system will be developed. The aim is to produce an easy-to-use tool that enables analysis of a cooling system for a defined area consisting of group of buildings. The deliverable *D5.1 District cooling planning tool framework and specification* marks the start of this task by describing the scope of the planning tool, the calculation methods used and the program implementation.

The development of the planning tool takes place within Work Package 5 (WP5). As stated in the Description of Work (DoW), the implementation of the WP will be carried out in parallel with WP3 and WP4 focusing on component predictive controllers and overall management strategy, respectively. The interaction between the WPs will be done by utilising lessons learned, information exchange and result comparison.

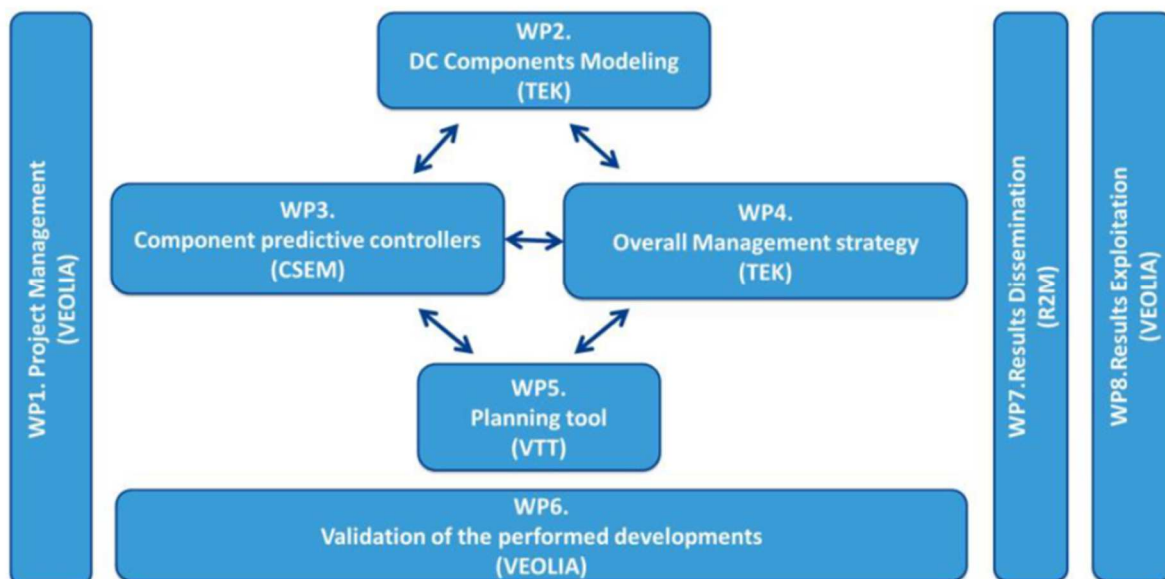


Figure 1. Work package structure.

The analysis carried out will take into account the energy, economic and environmental aspects of a cooling system. The performance analysis will provide information on primary energy consumption, emissions and costs of the system. Benefit and potential evaluation will compare a defined district cooling system against building and space specific cooling systems providing the same cooling service.

The results of the analysis will be combined to form a diverse set of key performance indicators (KPIs). The tool will be easily configurable in order for the user to make versatile analysis of impacts on system performance. This will be accomplished by letting the user to try out and compare effects of different assumptions on component specifications, costs and other input data.

Chapter 2 describes the investigated systems in detail, setting the boundaries and scope for the analysis to be carried out by the tool.

Chapter 3 introduces the methods used for energy, economic and environmental analysis.

Chapter 4 lists and describes the input data requirements set by the system definition.

Chapter 5 presents the program implementation itself. Programme structure, data storage solutions and GUI design will be described.

2 District cooling and reference system description

The systems investigated by the planning tool are defined within this Chapter. In overall, all the main components of a cooling system are included within the system boundary, but details on external processes are excluded such as industrial activities providing excess heat for absorption based cooling production or electricity production other than solar PVs and CHP units located on-site. Also, utilisation of excess heat from e.g. local heat production or condensing heat is partly excluded. Rate of utilisation is defined, but the heating system beyond is not considered in detail.

Based on the preliminary investigations, the most obvious difference between district cooling systems and building/space specific systems is that the cooling demand in terms of capacity is higher in building specific systems than in district cooling systems, and is likely to be even higher in space specific cooling systems. The system definition is further divided into elements that can be categorised as

- resources,
- energy supply,
- cooling production,
- distribution and
- consumption

Consumption is defined to include consumer equipment in general such as substation and method of cooling distribution within a building.

The classification is used further on in describing the elements or components.

Using a similar definition for district cooling systems and reference systems (i.e. building or space specific cooling systems) is a calculated choice. This enables similar analysis methods, data structures and finally algorithms to be used.

The calculation principles and general approach is given in Chapter 3 and the related input data in Chapter 4.

2.1 District cooling system

District cooling system is the most complete of the systems considered. Both the building and space specific systems can be seen as special cases of the district cooling system.

The resources considered in a district cooling system are fuels (fossil, biomass), solar irradiance and electric grid. These resources are in turn utilised in energy supply by CHP

units, boilers, solar collectors or photovoltaics (PVs), electrical energy, excess heat or industrial or natural sources of cooling. The last two could also be considered as resources.

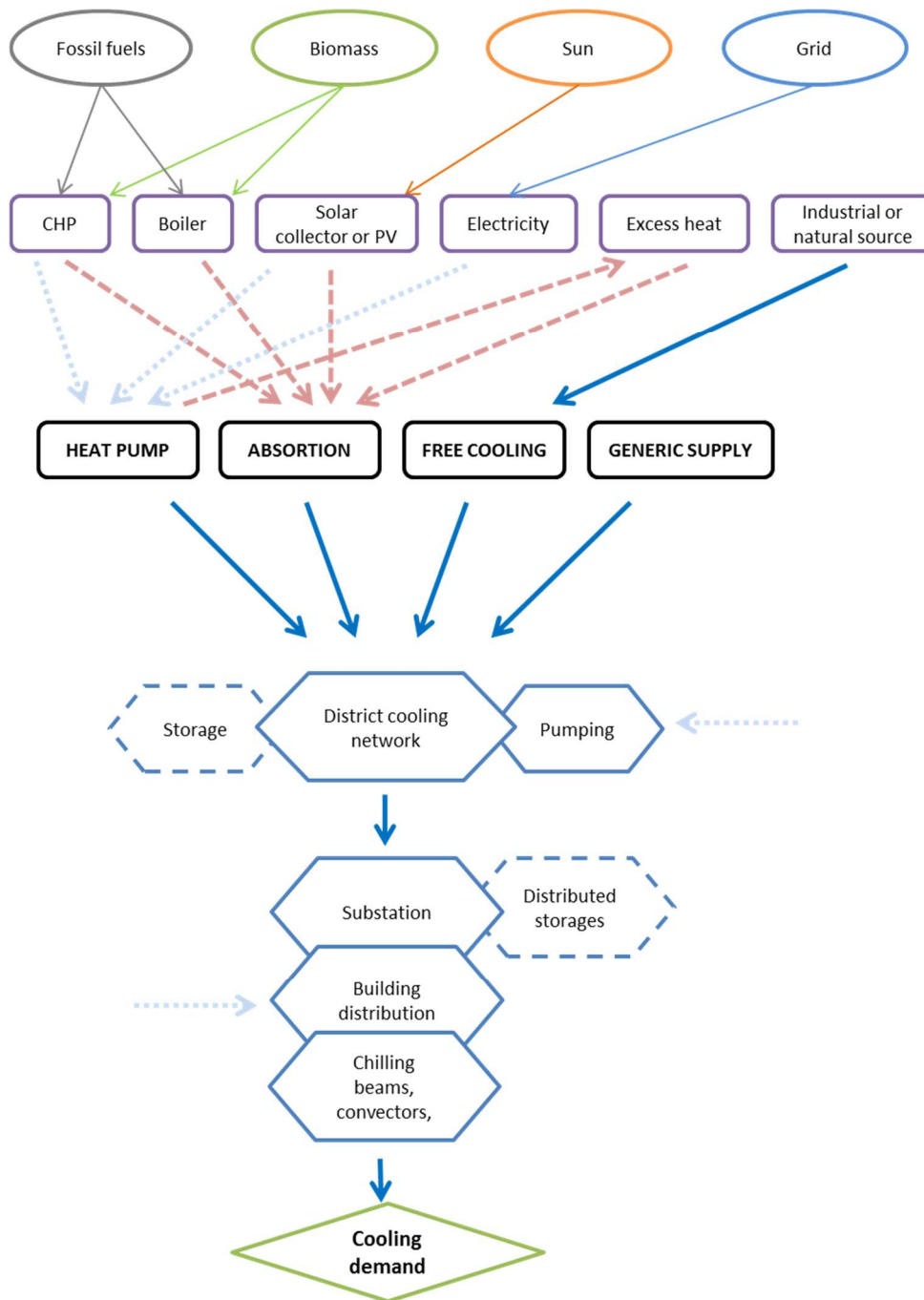
The output of energy supply can be electricity, heating or cooling. They are utilised in production of cooling by heat pump (electric chiller), absorption chiller, free cooling or by a special case called generic cooling supply that the user can freely configure by a set of parameters. The parameters of the other production technologies can be adjusted as well, but they are provided with a realistic set of default values.

The produced cooling is distributed to the consumers to satisfy a given consumption of all consumers through a network of pipes. The distribution component also includes optional centralised storage and pumps.

The consumption element consists of the main equipment needed by the consumer. This includes a substation, building level distribution system as well as cooling terminals. Consumption, i.e. cooling demand, is naturally the most important piece of input data for a specified system. Distributed storages are treated the same as centralised storages in the calculations. The definition will only affect the costs and description of the system.

This structure is illustrated in

Figure 2.



S

Figure 2. System definition for district cooling.

2.2 Building specific cooling system

The building specific cooling system is identical in definition compared to the district cooling system except that it does not include a distribution network and that the whole system consists of several sub-systems (i.e. consumers, individual buildings).

This means that with building specific cooling systems, the planning will include the definition of several different systems with different cooling demand. All systems are finally calculated together in the analysis.

Cooling demand in terms of capacity is presumably higher than in a district cooling system.

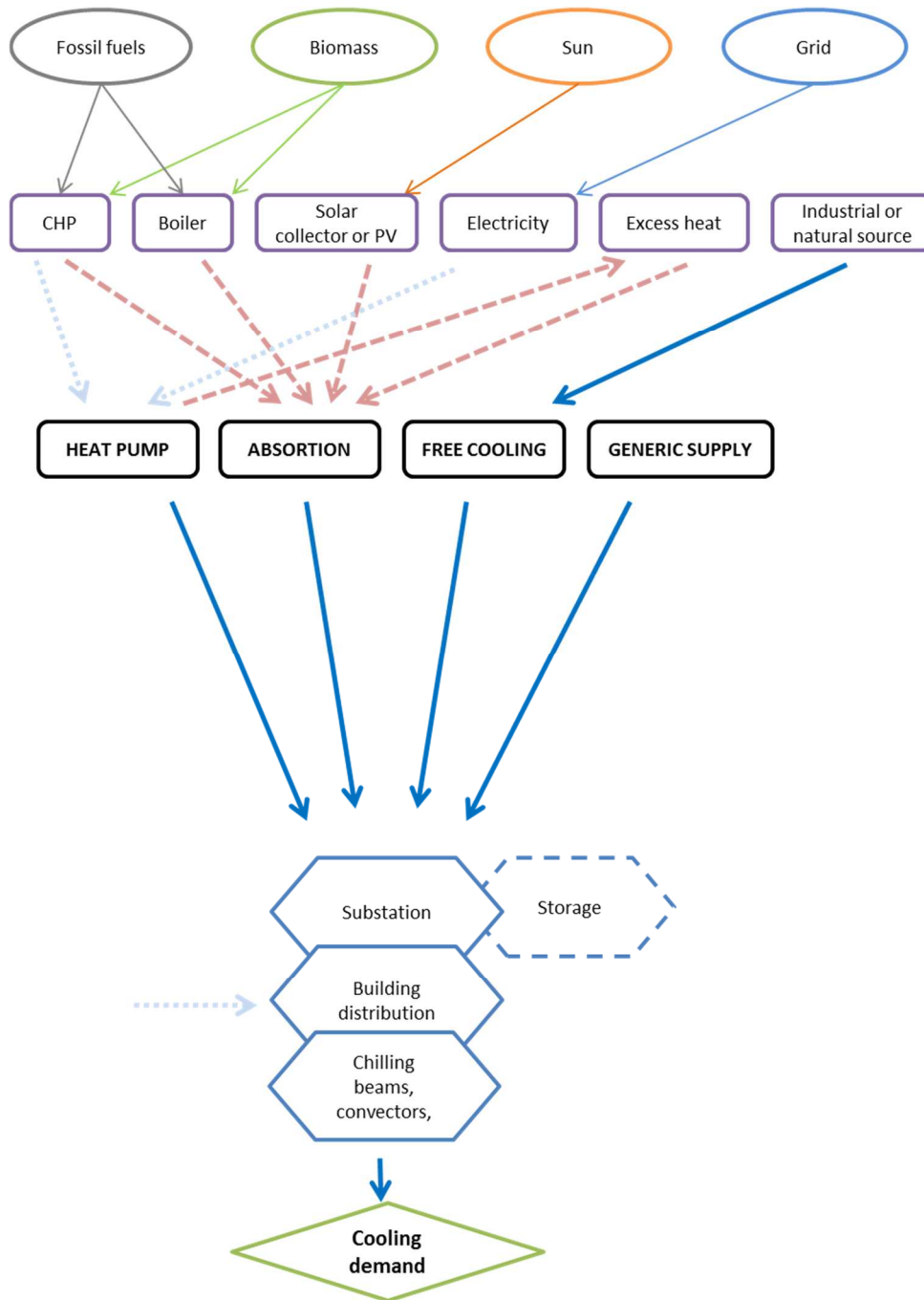


Figure 3. System definition for building specific cooling.

2.3 Space specific cooling system

Space specific cooling system represents the most distributed system of the three alternatives; every cooled space has its own cooling supply. In this case, most of the resources, energy supply and cooling production options are excluded. The only technology considered as a source of cooling is heat pumps.

Solar PVs are taken into account on a building level, not for single cooling units.

The space specific cooling system requires considerable input data in form of cooling demand. If such data is unavailable, a simplified method based on series of assumptions will be used to generate the demand. The cooling demand in terms of energy is not different from a case of building specific cooling, but as with comparison between district cooling and building specific cooling, the capacity and efficiency is very likely to be different.

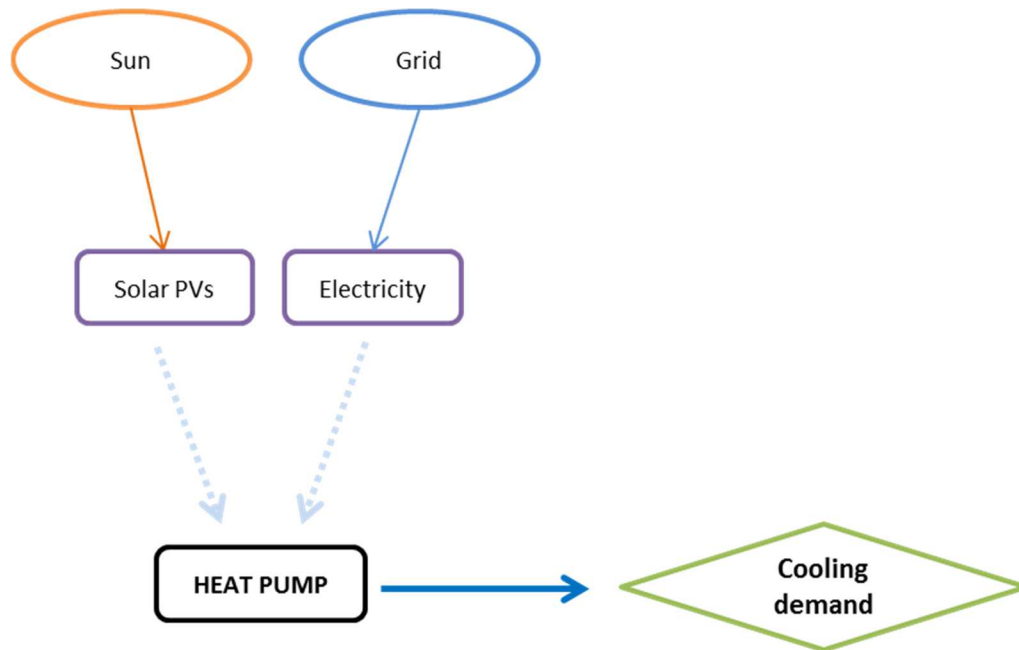


Figure 4. System definition for space specific cooling.

3 Methods

This chapter describes the methods used in analysing the performance of the system from energy, economic and environmental points of view.

3.1 Overall approach

The analysis process consists of three interlinked phases; energy analysis (Chapter 3.2), economic analysis (Chapter 3.3) and environmental analysis (Chapter 3.4).

The general idea is first to define the system being investigated and prepare the required input data (Chapter 4). Then, to find out how the system is operated and what is the resulting total energy consumption. Using both information on the system components (investment) and their energy consumption (operational costs), the economic feasibility can be studied. On the other hand, energy consumption and component specification is used to calculate the climate impact in terms of GHG emissions. These emissions are calculated using life cycle assessment both for operational phase and for production of components, i.e. materials used.

The results from the different analysis phases are all used in calculation of a combination and comparative indicators (Chapter 3.5). First is an indicator in which two results are combined, e.g. cost of cooling. The second is an indicator where DC is compared to the reference system, e.g. emission reductions enabled by the investigated DC system.

The overall approach is illustrated in Figure 5.

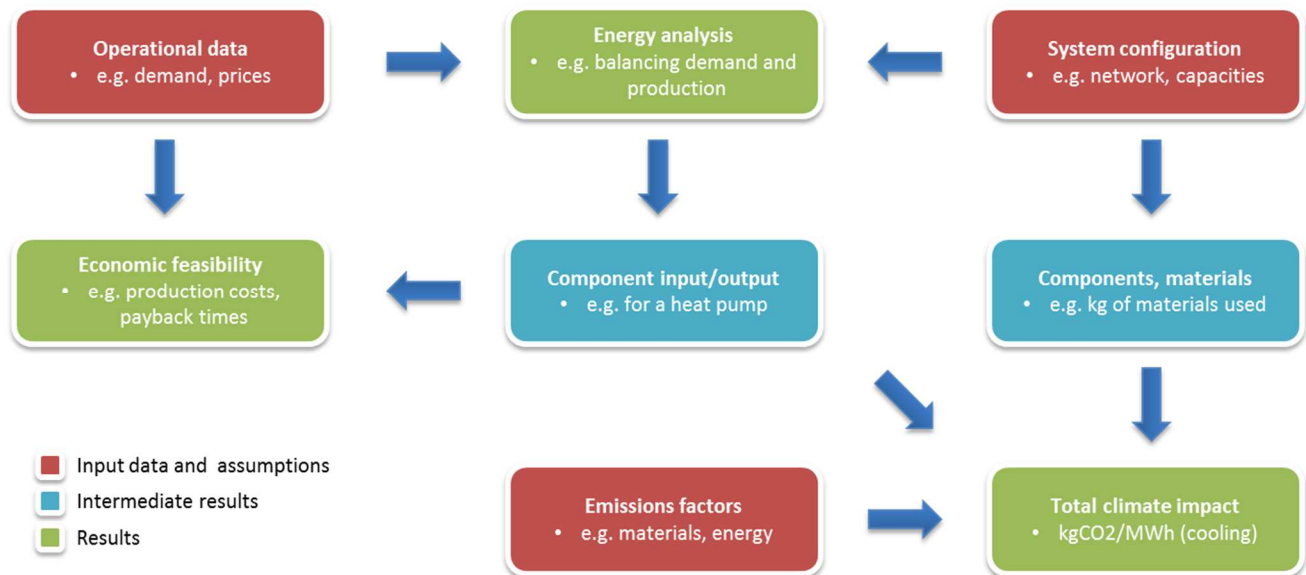


Figure 5. Overall description of the analysis to be carried out.

3.2 Energy analysis

The objective of the energy analysis is to find out energy consumption needed to satisfy a given cooling demand by the specified system.

Energy analysis requires technical specification of system, consumer specific cooling demand as time series and costs of resources and energy supply as input data. This information is used to dynamically generate a simple optimisation model that can represent either a linear or a mixed-integer linear optimisation problem. The Python based library used for this purpose is Oemof¹ (“Open Energy System Modelling Framework”).

This dynamic generation of the model means that specified resources, energy supply, cooling production, distribution system and consumption parameters are used to generate a model that includes the components present in the studied system. If the parameters change, or new components are added, the model can be generated again. The model structure is basically the same as what is described in Chapter 2. The input parameters are described in Chapter 4.

As the optimisation is based on minimising the operational costs of the system, energy analysis can in fact be considered as a techno-economic analysis. The value of the objective function of the optimisation is the total operational cost of running the system.

However, possibility of adding weighting functionality is envisaged to allow for:

- better consideration of client’s preferences, and
- studying greater amount of parameter combinations, including variation of weights of e.g. costs and energy consumption.

¹ <http://oemof.readthedocs.io/en/stable/index.html>

The optimisation results include time series on how components within the system are operated and how much resources are used, e.g. cooling supply by individual chillers and electricity used by these chillers. All the energy flows within the system can be distinguished, processed further and used in reporting of results.

Results represent a single year of operation, a so-called representative year. In both economic and environmental analysis, a longer time period is investigated based on the results of the energy analysis for this representative year. If the input assumptions change between years, e.g. new electricity prices or emission factors are assumed every five years, multiple representative years can be analysed.

The energy analysis for district cooling systems and building/space specific systems differs in a way that for district cooling simply one system is investigated. For building specific cooling systems, the number of systems is same as number of buildings included in the analysis. For space specific cooling system analysis, the number of individual systems is even higher but many can be considered to be identical in terms of cooling demand and technical specifications. The results for building/space specific analyses are finally summed up to represent the operation of a whole system comparable to a district cooling system. This approach is visualised in Figure 6.

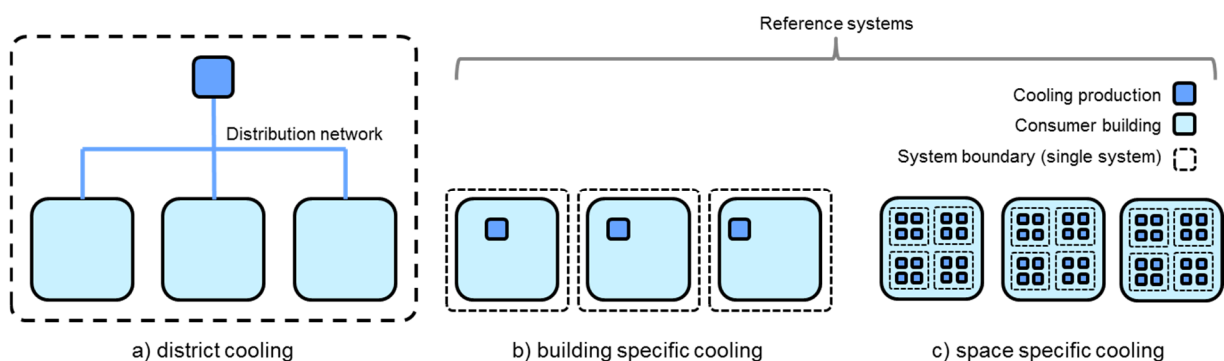


Figure 6. Simplified illustrations of the systems investigated.

3.3 Economic analysis

In economic analysis the results of the energy analysis are combined with operational and, more importantly, investment costs. Together with results from energy analysis, costs of the cooling supply (€/MWh) can be calculated and compared with different cooling solutions; district, building and space specific cooling systems.

Operational costs of running the investigated cooling systems during “a representative year” (see previous chapter on energy analysis) are added to the investment costs. This is carried out for a specified number of years, e.g. 20 years as default. The analysis takes into account the discount factor (5 % as default) to calculate the net present value (NPV) of the future costs. If price for cooling energy sold is defined, the pay-back time of the investment can be calculated. The revenues from the cooling energy sold are multiplied by the discount factor.

In addition to the KPIs such as cost of cooling supply in €/MWh, the results can also be visualised as cumulative costs or profitability of investment curves. These can be used to

compare the results for different cooling systems, or different configurations of the same type of a cooling system. The profitability of investment curve also includes revenues for the sold cooling energy enabling a pay-back time to be calculate. This can also be seen in the result graph as the point where a corresponding line intersects zero in y-axis. Figure 7 presents an example of this type of visualisation.

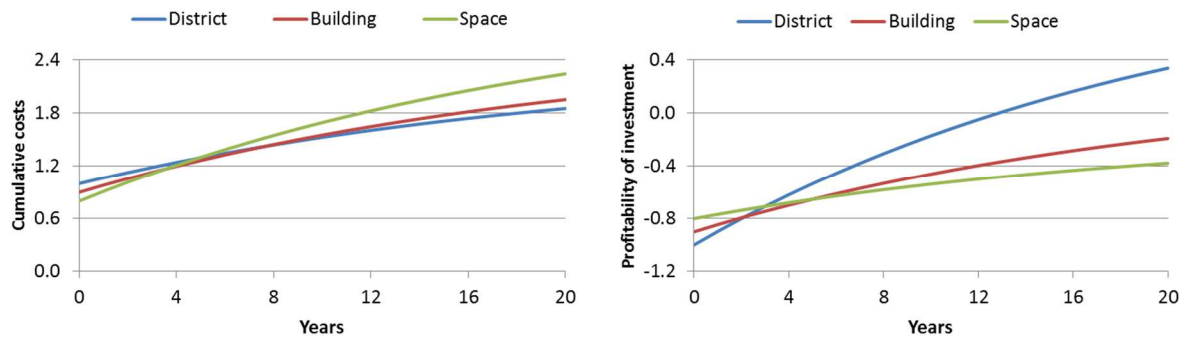


Figure 7. Examples of curves representing cumulative costs (left) and profitability of investment.

3.4 Environmental analysis

The environmental analysis in the planning tool focuses on climate impacts of the district cooling systems. The planning tool will enable assessment of the GHG emissions of the studied district cooling system. It will also allow for comparing the emission impacts of planned district cooling systems to reference cooling systems (e.g. space specific cooling). Thus, the tool will provide information on potential emission savings achieved with the district cooling systems. The climate impact assessment will follow the framework of life cycle assessment (LCA). The following sections describe how the climate impact assessment will be performed in the planning tool.

3.4.1 Principles of life cycle assessment (LCA)

Life cycle assessment (LCA) is a widely utilised tool for systematically evaluating the potential environmental impacts of a product or a system throughout its whole life cycle. The principles of LCA have been standardised in two ISO standards, ISO 14 040 and ISO 14 044 [1,2]². In LCA, all the inflows and outflows of substances are considered, and the impacts of these are analysed. Typically, an LCA covers the life cycle of a product from ‘cradle to grave’ but it can also be limited to a certain part of the life cycle, for instance the use phase. LCA can help to recognise the most emission intensive components and functions of a system and thus enables efficient emission reduction measures. As LCA concentrates on all the inflows and outflows of substances it also reduces the risk of problem shifting, i.e. situations where an improvement in one part of the life cycle leads to weakening in another part.

² ISO 14040 provides a clear overview of the practice, applications and limitations of LCA to a broad range of potential users and stakeholders, also those with a limited knowledge of life cycle assessment, while ISO 14044:2006 has been designed for the preparation, execution and critical review of life cycle inventory analysis. It also gives guidance on the impact assessment phase of LCA and on the interpretation of LCA results, as well as on data collection. The standards complement one another as 14040 sets the basics and 14044 goes into more detail.



Figure 8. Principles of life cycle assessment (LCA).

In an LCA study, the emissions of a system are studied per functional unit, meaning the measure of the function of the studied system (Figure 8). The functional unit provides a reference to which the inputs and outputs can be related, and by which the different systems can be compared to each other.

3.4.2 Climate impact assessment in the planning tool

In LCA, a system boundary defines the limits of which parts of the system are included in and which parts excluded from the study. In the modelling tool, the system boundary covers the district cooling system, including the local resources and energy supply, cooling production, distribution network and consumer. (Figure 9) Both, the emissions related to the establishment and use of the system will be analysed. For the LCA all the inputs to and outputs from the system are studied. In practise, some minor flows of the system are often cut off, as their contribution to the final result is irrelevant (e.g. less than 1%).

In the planning tool, the aim is to include all major energy and material flows related to the components needed for the district cooling system. However, some minor components will be excluded, as their contribution to the final results is expected to be insignificant. For this, the 1% cut-off rule will be applied in the tool, i.e. those processes whose contribution to the total emissions of the cooling system is estimated to be less than 1% will be excluded. The functional unit is chosen to be one MWh of cooling provided. This means that the emissions are expressed as kg CO₂eq. / MWh cooling provided.

Normally, an LCA study considers the whole life cycle until the disposal of the product studied. The tool is planned to include the emissions related to:

- Manufacture of major components (and raw materials)

- Construction of district cooling network (pipes + construction work)
- Emissions of utilisation phase

For simplicity, the tool is planned to exclude the emissions related to:

- Smallest technical components (contribution to the total emissions less than 1%)
- Installation of components (e.g. energy used by manpower)
- End of life emissions (emissions in landfill/recycling/recovery)

The emissions of the utilisation phase refer to the emissions of energy consumption in the studied systems. These are for example the emissions of fuels or electricity used in the cooling production. The district cooling systems and the components utilised are supposed to be long-lived. For the technical components, the emissions of production are allocated over 20 years, which is expected to be their average life time. For the distribution network (pipes), the emissions are allocated over 50 years life time. It is challenging to know how the components would be treated at the end of their life cycle, and what are the recycling possibilities and emissions/emission benefits at that point. Thus, for simplicity, the end of life emissions are left outside the system boundary of the planning tool, and only the establishment and use phase of the district cooling and the reference system are included in the assessment.

LCA studies can be roughly divided to two different types of analyses based on their approach to data collection and system modelling. In the so-called attributional LCA, the average emissions of a system are studied, whereas in so called consequential LCA the marginal emissions due to a change in the system are studied. In the planning tool, we follow the principles of attributional LCA and define the average emissions of the district cooling systems and the reference systems³. This will enable the comparison of the different choices to produce a certain amount of cooling. For attributional LCA, the use of average emission data is typical. Here we use for example the average emissions of electricity production in a region, if grid electricity is used. If electricity is provided by a system specific for the district cooling system (e.g. solar panels, boiler, etc), the specific emission of electricity production can be used.

³ In a planning tool like the one developed in this project, the assessment of overall consequences of a decision to build a district cooling system would be very challenging, and e.g. energy system modelling would be needed to track the market impacts.

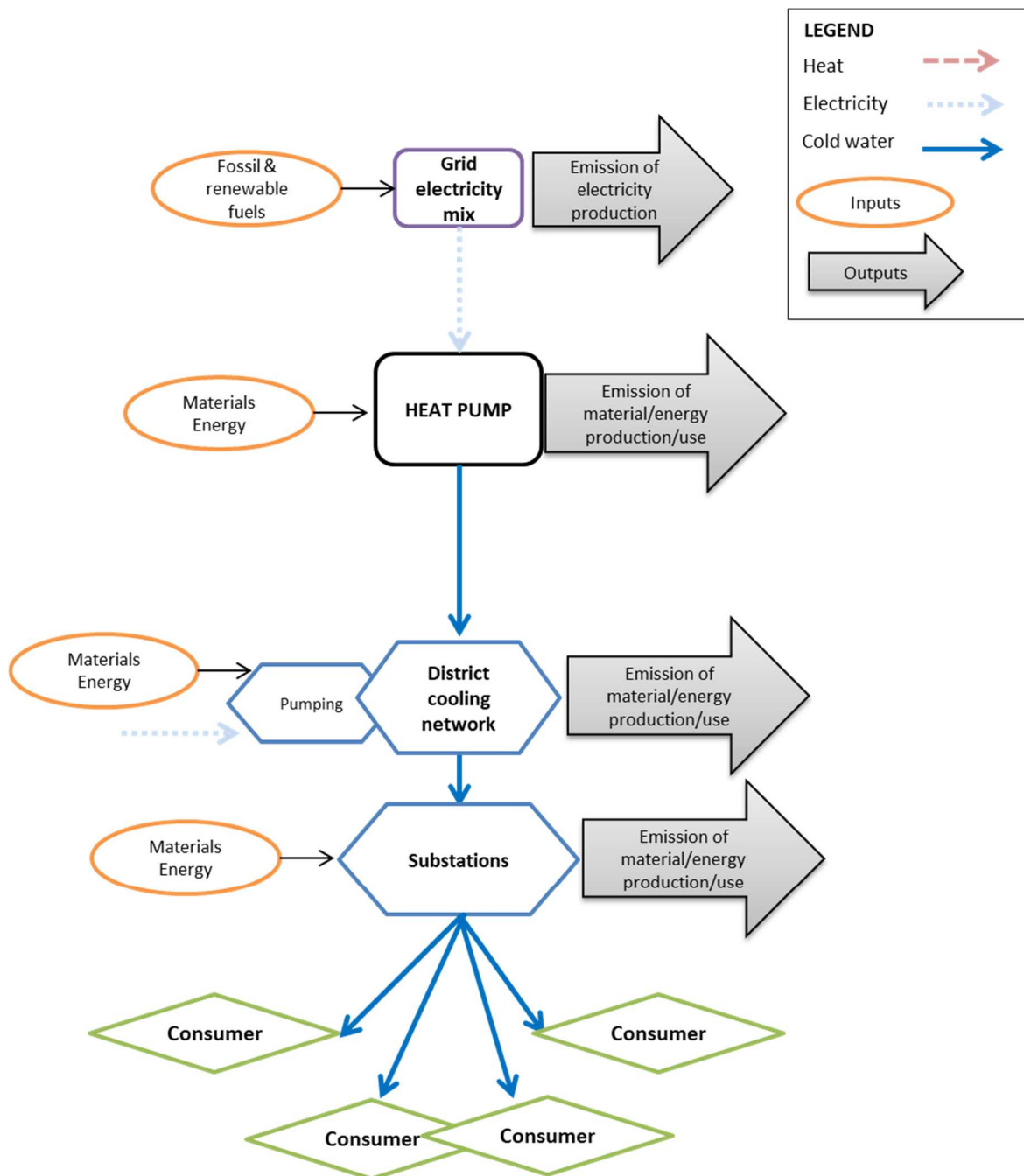


Figure 9. Framework for an LCA study for an exemplary district cooling system. Energy and material flows of system components are assessed to evaluate the GHG emission flows and the total emissions.

3.4.3 Data and the emission calculations

The data for the LCA study will be collected from literature and from LCA databases. As the planning tool will be an open access tool, also the LCA data and data sources will be openly reported. In some cases, however, if no suitable data is found outside commercial LCA databases, we may need to offer only aggregated data (e.g. we would show the emission data on the level of a technical component unit, not per individual raw materials used). This will be negotiated with the data providers, when the specific data needs are defined during the tool development.

Depending on the data availability the emission data related to the components and energy consumption can be collected in several forms:

- **kg CO₂/unit**, if an existing LCA study can be found for the specific technical component. If the size of the component is known, e.g. chiller of 10 kW, then the emissions can be converted to **kg CO₂ / kW** and scaled for other sizes of units, if no more precise estimates are found.
- **kg CO₂/kg** of raw material. In this case the composition of the raw materials used in a technical component needs to be known, e.g. based on the product declaration (e.g. 70% steel, 25% aluminium, 5% copper).
- **kg CO₂/MWh** for the electricity consumed.
- **g CO₂/MJ** for the fuels consumed.

After the data collection, the calculation of the GHG emissions is straightforward. For example, when the emission per component unit E_C are known, the total emission of these components E_{tot} can be calculated as:

$$E_{tot} = i * E_C,$$

where

i is the number of components in the system.

When emissions per raw material and the amount of raw material used are known the total emission of a component can be calculated as:

$$E_{tot} = \sum_{i=1}^n (E_{Mn} * m_{Mn}),$$

where

n is the specific raw material,

E_{Mn} the emission of production of this raw material [kg CO₂/kg], and

m_{Mn} the mass of the raw material needed in the component [kg].

The emissions of energy consumption can be calculated as:

$$E_{tot} = E_E * Q,$$

where

E_E is the emission of Energy [gCO₂/kWh or gCO₂/MJ]

Q is e.g. the energy consumption [kWh or MJ].

The total emissions of the system E_{system} will then be calculated as a sum of these emission components E_{tot} :

$$E_{system} = \sum_{i=1}^n E_{tot}.$$

The total GHG emissions over the whole life cycle of the system will be expressed per MWh cooling produced [kg CO₂/MWh]. The planning tool will gather together the information of the components needed in the district cooling system and the reference system. This information

will be combined with the emission data. The tool will then enable comparison of the emissions produced by the district cooling system and the reference systems. It will also show how the emissions are formed, e.g. the contribution of different components and the energy consumption during the use. In addition, the user can calculate additional indicators, including the average annual emissions (allocated emission to components) / average annual cooling produced, and the distribution of the emissions over different life cycle phases

In the planning tool, the user will select the parameters to be used in his system. The tool will provide LCA data for base cases, but the user can also include also own emission data.

3.5 Results processing

The main results from the different analyses are primary energy consumption, costs and total emissions. These can be combined with cooling demand to form new sets of more descriptive KPIs like e.g. costs per unit of cooling or emissions per unit of cooling.

When DC system is compared to the reference systems or different configurations of alternative DC systems are compared, even more useful results can be generated. Both main results and their combinations can be compared. These turn into KPIs such as primary energy savings, costs cuts and emission reductions. These can further be combined to produce values such as cost of primary energy savings or emission reductions.

The final set of KPIs will be decided based on testing, literature review and by comments from the members of the project group.

4 Input data

The analysis included in the planning tool requires a considerable amount of input data. Wherever possible, default values are made available and used if no additional information is available. However, cooling demand, network structure, cooling technology and also energy supply in certain conditions must always be defined by the user. Description of the needed input data is given in Table 1.

Table 1. List of required input data using categories identified in system definition.

Resources	
Description	Source and type of primary energy.
Parameters defined	Heating values of fossil or biomass based combustible fuels, solar irradiation potential* and availability*, prices* of fuels and electricity, specific emissions of different fuels and grid electricity.
Examples	Fossil fuels, biomass based fuels, grid connection, solar irradiation.
Energy supply	
Description	Local energy supply utilising available resources.
Parameters defined	Capacities for heat or electricity production, temperatures* of available sources of heating or cooling, availability of energy supply*, efficiencies, related investment costs, specific emissions of material or equipment.

Examples	CHP units, boilers, solar PVs or collectors, electricity supply, excess heat, industrial or natural source of cooling.
Cooling production	
Description	Technology for the cooling supply.
Parameters defined	Capacities and efficiencies (heating or electricity per produced unit of cooling), excess heat output, investment and maintenance costs, specific emissions of material or equipment.
Examples	Electric chillers, absorption chillers, free cooling using a natural or an industrial source, generic cooling supply technology with freely adjustable parameters.
Distribution	
Description	Specification of the distribution system for district cooling.
Parameters defined	Structure, topology and dimensions of the network, distribution temperatures*, ambient temperatures*, storage in terms of capacity and dimensions, investment and maintenance costs, specific emissions of material or equipment.
Examples	Connections between nodes forming a network of pipes, pipe materials and dimensions, insulation materials and dimensions, soil temperature, storage charging and discharging capacities, storage size, storage materials and dimensions.
Consumption	
Description	Consumption of cooling and specification of related equipment.
Parameters defined	Cooling demand*, connection capacity, number of cooling terminals within the building, distribution temperatures, investment and maintenance costs, specific emissions of material or equipment.
Examples	Substation capacities, cooling distribution specification by e.g. chilling beams, convectors.

The input data can be defined as scalars, time series or in some cases either one of these. The parameters that can be defined by time series are marked by an asterisk (*) in the table. The time series consist of hourly values for a specific parameter and are have a length of one year. Only exception to this are future projections of electricity prices and specific emissions of grid electricity. These have resolution of one to five years.

The predefined default values for parameters are stored in .csv (“comma-separated values”) format where they can be accessed by the planning tool and be easily modified by the user. The predefined parameters represent normal conservative values for specific technologies, e.g. for efficiencies CHP units and electric chillers or for distribution pipe structure and materials, but some values such as capacities or pipe lengths always need to be defined by the user. The predefined parameters can of course be modified if needed. The aim is to provide an easy-to-use tool that enables reliable analysis that can be made even more accurate if more detailed data is available.

5 Planning tool implementation

The description of planning tool implementation contains information on the data structure and storage solutions to be used in the tool. The proposed approach defines a framework for the implementation process with some modifications and additions possible. This is

especially true for the presented GUI design; the main functionalities are clear, but the layout and appearance might change if a more reasonable or clearer solution is found.

The implementation will also be influenced by comments and suggestions from testing group formed by the project consortium.

5.1 Data structures and storage

The data structure within the planning tool is implemented by using object-oriented programming. The individual components within the system are represented as instances of objects defined as in the system description. A class representing a whole cooling system includes lists of these instances of components as variables. An overall master class can include one (district cooling) or several (building or space specific cooling) systems.

This idea of nested, classes is illustrated in Figure 10.

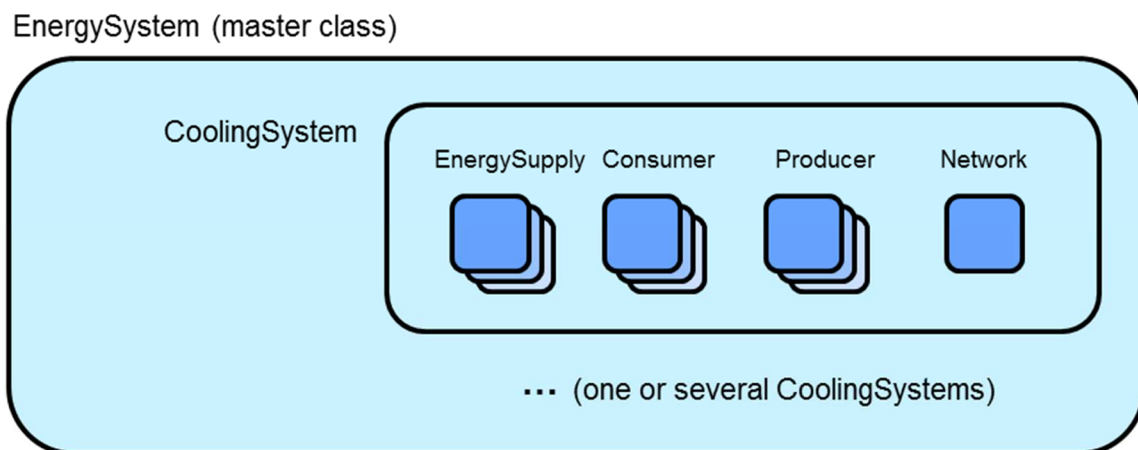


Figure 10. Hierarchy of nested, enclosed classes.

The classes containing the object specification also include functions for manipulating and processing the data within. The master class includes the main analysis related functions.

Following table lists the main classes to be included in the implementation. Supporting variables e.g. for identification and processing are omitted. The list of classes and variables is preliminary and may change if considered reasonable during the implementation phase.

Table 2. Definition of classes and their main variables in the planning tool implementation.

Class	Variables	Description
EnergySystem	systems resources availability	A master class containing one or several CoolingSystems and variables for resources and their availability. This is also where analysis (energy, economy, environment) functions are defined.
EnergySupply	capacity elec_efficiency heat_efficiency cool_efficiency	A class describing the different energy supply technologies, their efficiencies for producing electricity, heating or cooling (in case of a natural or an industrial source) and the resource used by a specific technology.

	resource	
CoolingSystem	energy_supply consumers producers network	A class representing the whole cooling system with energy supply, consumers, producers and network defined.
Node	location	A superclass for Consumer and Producer classes with the location of the node defined.
Consumer	demand supply_temp return_temp	A class for modelling the consumer with cooling demand and internal supply and return temperatures defined.
Producer	capacity elec_consumption heat_consumption supply_temp return_temp	A class representing a cooling production technology with a given capacity and electricity/heat input per produced unit of cooling. Supply and return temperatures defined.
Network	structure node_types	A class containing data on distribution network structure (i.e. which pipes connect which nodes within the network) and definition of the nodes (a consumer, a producer or a connecting node)
Resource	type energy_content availability capacity	A class that defines the type and energy content of a specific resource used by energy supply. The availability is used for addressing the nature variable resources such as solar irradiation and the capacity sets maximum constraint on its use.

Default values for selected variables and time series are stored and retrieved from dedicated .csv files when needed, and defined in the variables within the presented classes.

5.2 GUI design

Main purpose of graphic user interface (GUI) of the planning tool is to manage model data and structure and pass these values into optimization module of the tool, and also import result data from optimization in order to form easy to read result summary. Flow of data in planning tool is illustrated in Figure 11. GIS tool of GUI is utilized in forming simple but functional network of cooling system based on map file from the analysed area. GUI is constructed by using PySide library which provides LGPL (The GNU Lesser General Public License) -licenced Python bindings for the Qt (cross-platform application framework). It must be noted that figures here illustrating GUI of planning tool are merely outlines based on planned functionalities of planning tool. Usability of GUI is developed dynamically by using project members as testers.

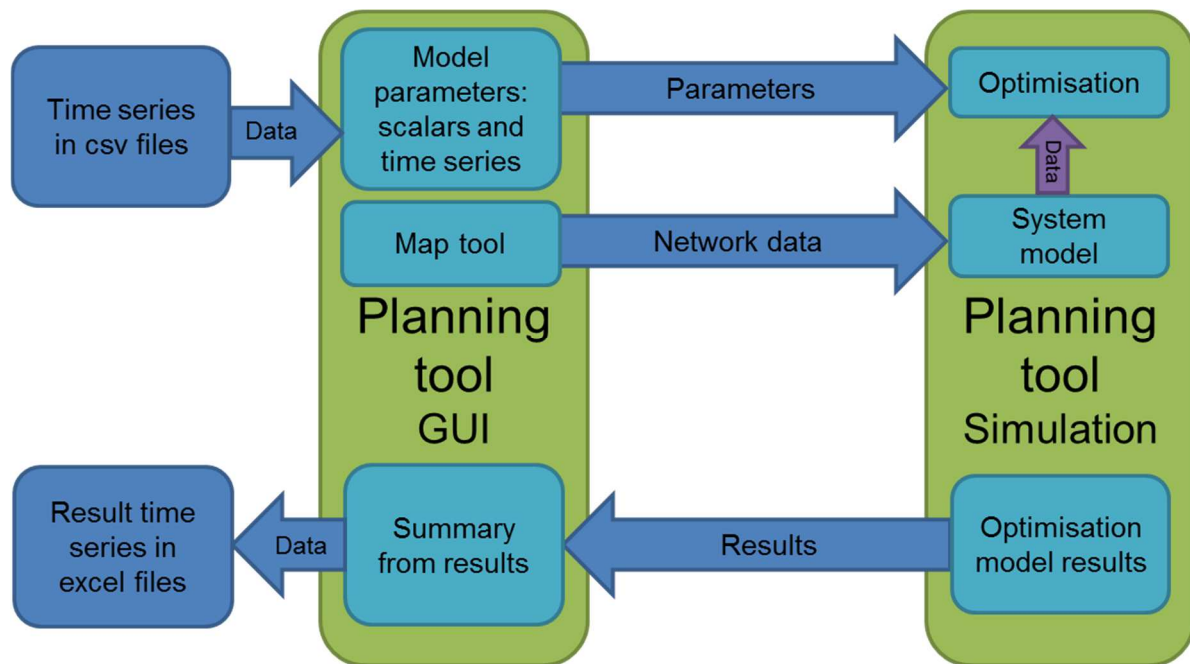


Figure 11. Flow of data in planning tool.

GUI of planning tool is divided into 5 tabs with different functionalities. In Analysis Tab illustrated in Figure 12 user can select cases and scenarios and run analysis. After optimisation process has provided result data, result summary is presented here and can be exported into csv or pdf file. Functionalities of Analysis Tab are listed in Table 3.

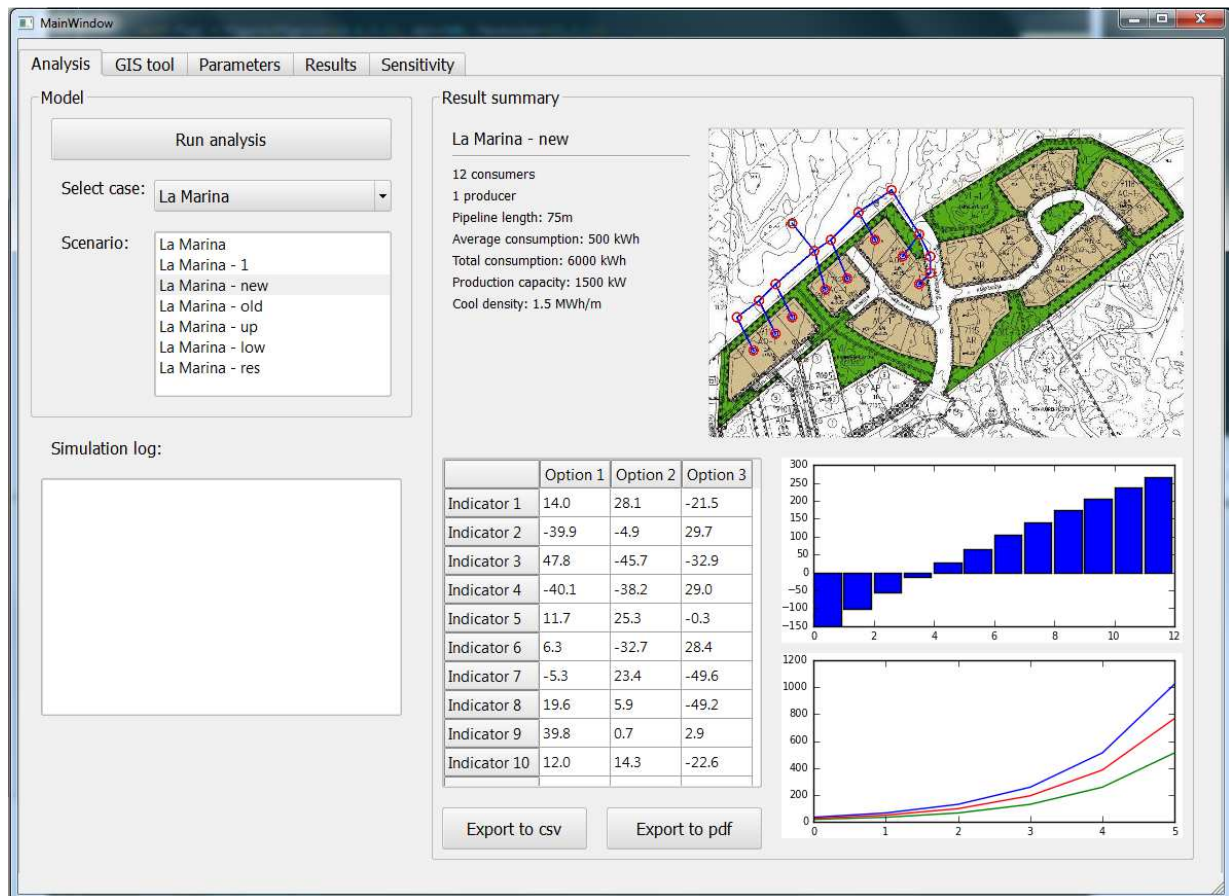


Figure 12. Analysis tab.

Table 3. Functionalities of Analysis tab.

Functionality	Description
Select case	User can select a case to run analysis for from set of cases created in GIS tool tab.
Select scenario	User can select a scenario created in parameter tab for selected case, varying different parameters in analysis.
Run analysis	User runs analysis and launches optimization for selected case and scenario by sending network data and parameter data to optimization tool.
Log window	Progress of optimization tool is recorded here
Result summary	After optimization tool has finished, results are processed and summarized in this section. Summary includes map, details of consumers and pipeline, techno-economic and environmental graphs and table for key indicators in the case of all cooling options.
Export csv	User can export summary and time series results into case specific csv file.
Export pdf	User can export a 1-2 page pdf summary from results.
Select case	User can select a case to run analysis for from set of cases created in GIS tool tab.

In GIS Tool Tab illustrated in Figure 13 user can construct simple network of cooling system consisting of producers, consumers and pipeline by using guidelines illustrated in Figure 14. User can import map from case folder with coordinate information in order to create new case or load existing case. In forming the network user can define details of consumer or producer nodes and properties of pipeline element added. GIS tool exports data from network into text files utilised by analysis tool. Main functionalities of GIS Tool Tab are listed in Table 4.

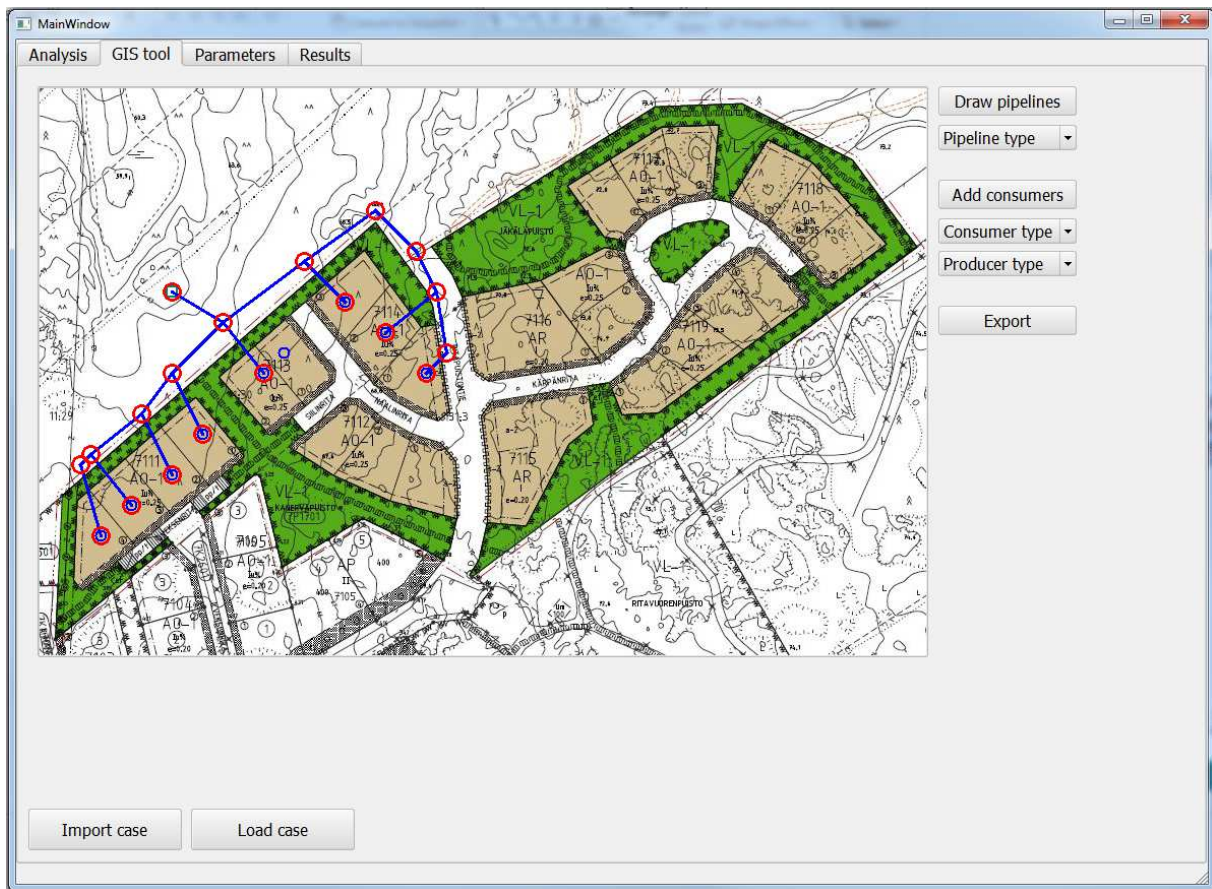


Figure 13. GIS Tool tab.

Table 4. Functionalities of GIS Tool tab.

Functionality	Description
Map screen	Here user constructs cooling network including consumers, producers and pipeline by using map file as background.
Import case	User can import new map file in order to create new case. Imported files (map file and coordinate information) locate in case specific folder.
Load case	User can load existing case for editing.
Draw pipelines	After pressing this button user can draw pipeline into map screen. Pipe start and end snaps to 20 pixel grid.
Pipeline type	User can select pipeline type before adding elements. Type specific details can be edited in user interface or configuration files.

Add consumers	User can add consumers (left mouse button) or producers (right mouse button) into map screen. Consumer and producer nodes snap to 20 pixel grid.
Consumer type	User can select consumer type before adding points. Type specific details can be edited in user interface or configuration files.
Producer type	User can select producer type before adding points. Type specific details can be edited in user interface or configuration files.
Export	Data from constructed network are exported to text files. Network data consists of pipeline elements (type, length, start node, end node), consumer points (type, node), producer points (type, node) and node information (code, location).

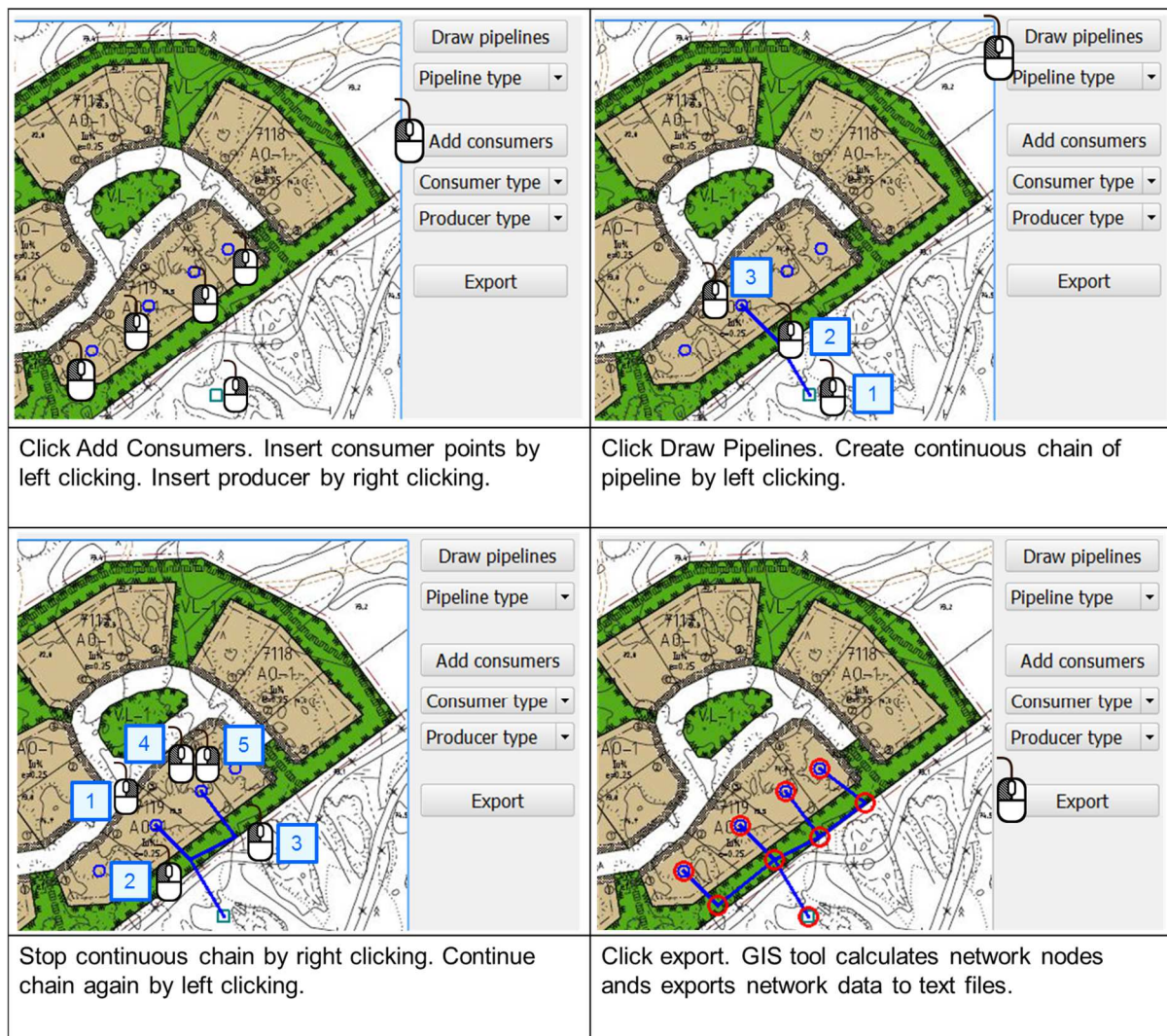


Figure 14. Guideline for using GIS tool in order to construct cooling network.

In Parameters Tab illustrated in Figure 15 user can edit and manage parameters of the model. In these tables parameters are divided into energy, economic and environmental parameters with sources to parameters represented as links. Model time series are also managed in this tab. Main functionalities of Parameter Tab are listed in Table 5.

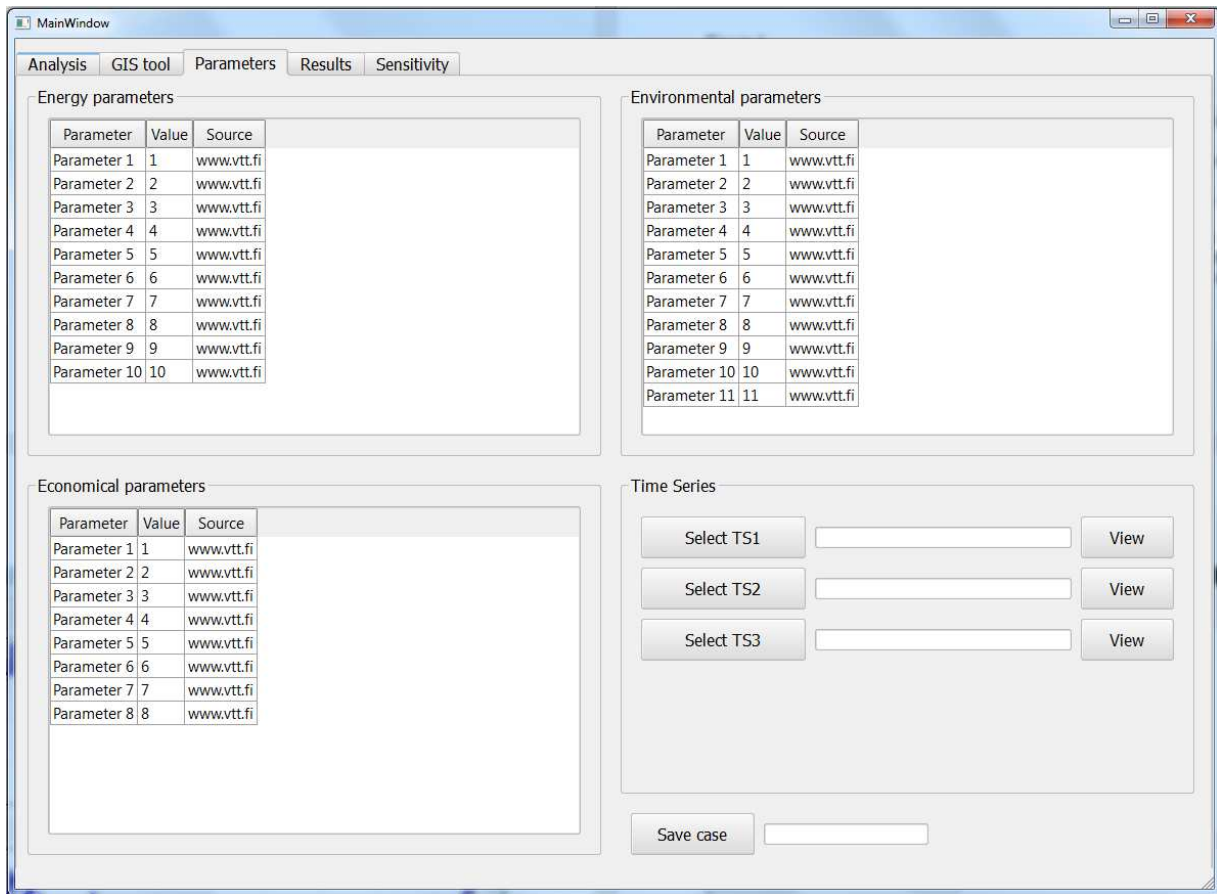


Figure 15. Parameters tab.

Table 5. Functionalities of Parameters tab.

Functionality	Description
Energy parameter table	Energy related parameters can be edited here, including links to source.
Economical parameter table	Economy related parameters can be edited here, including links to source.
Environmental parameter table	Environment related parameters can be edited here, including links to source.
Time series management	Data for time series from files are selected here. Time series parameters can be examined here.
Save scenario	Parameters in one case can be varied and saved as a separate scenario.

In Results Tab illustrated in Figure 16 user can view result time series provided by simulation. There are two graphs for time series and user can select time series from list for each graph. Main functionalities of Results Tab are listed in Table 6.

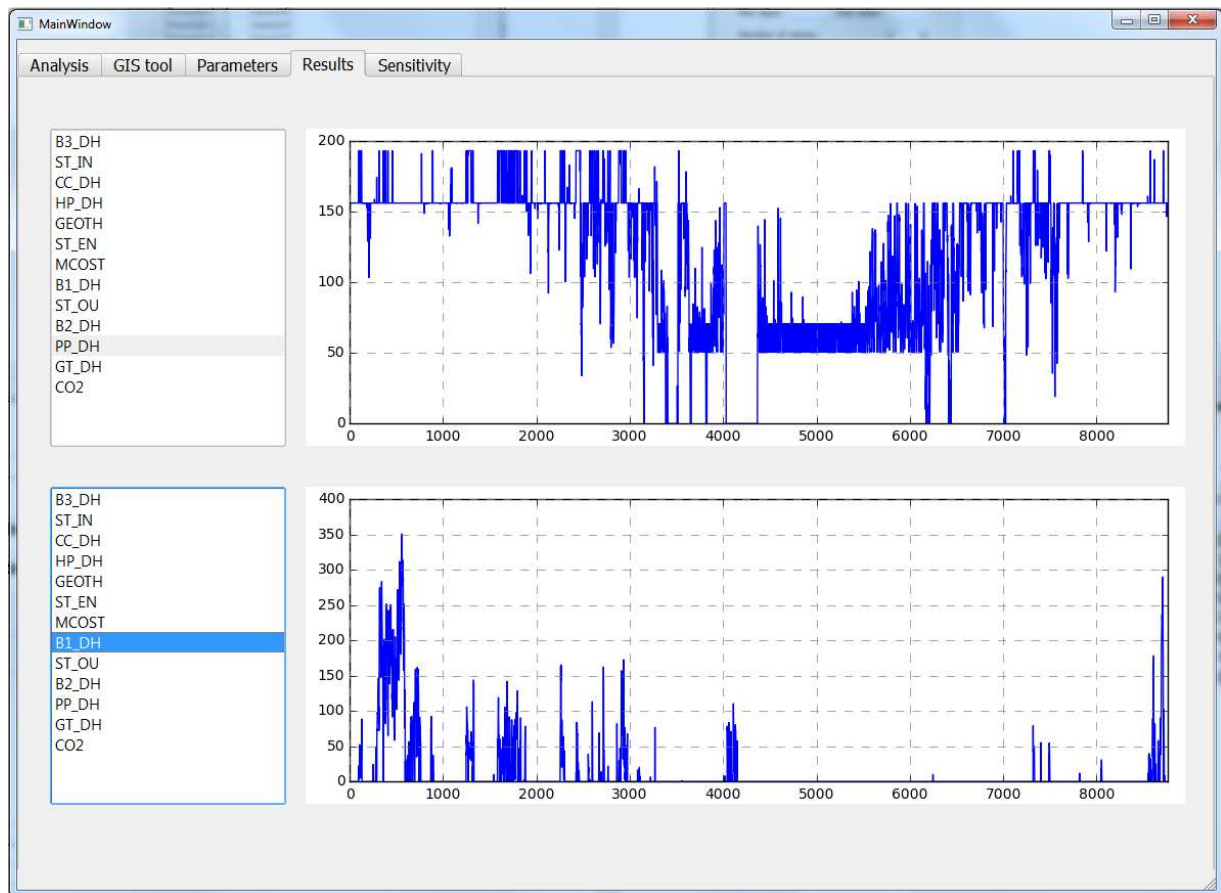


Figure 16. Results tab.

Table 6. Functionalities of Results tab.

Functionality	Description
Time series result graphs	2 graphs showing hourly time series of results.
Select time series	User can select from list time series showed.

In Sensitivity Tab illustrated in Figure 17 user can perform sensitivity analysis on selected case in terms of one model parameter. User can select parameter and variation of the corresponding parameter and run sensitivity analysis, in which optimisation is run several times with different parameter values. Results from sensitivity analysis can be viewed in tables and/or graphs and can be exported to csv file. Main functionalities of Sensitivity Analysis Tab are listed in Table 7.

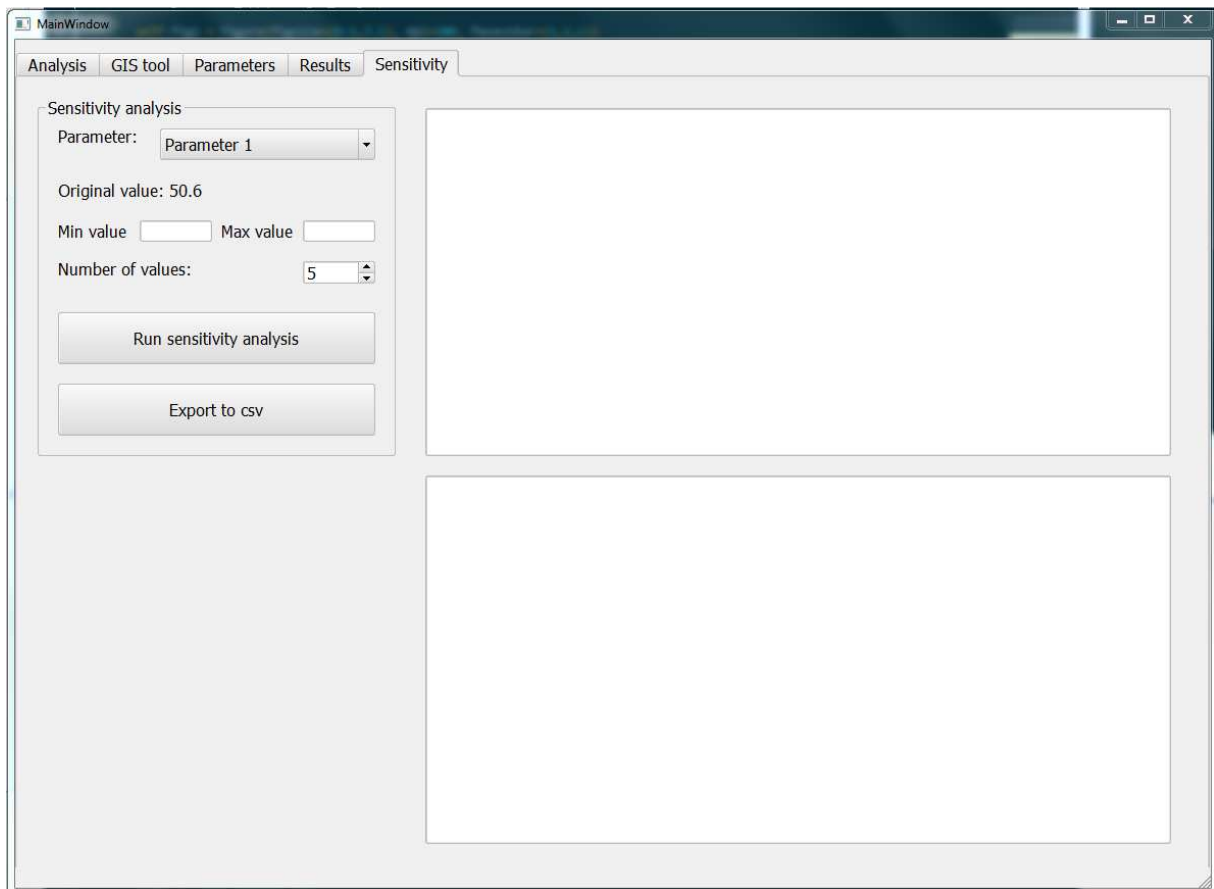


Figure 17. Sensitivity Analysis tab.

Table 7. Functionalities of Sensitivity Analysis tab.

Functionality	Description
Select parameter	User can select model parameter for which sensitivity analysis is performed
Set minimum value	User selects minimum value for parameter
Set maximum value	User selects maximum value for parameter
Set number of values	User selects how many sensitivity values are set for parameter between minimum and maximum.
Run sensitivity analysis	Sensitivity analysis starts with GUI passing required number of parameter sets to simulation.
Export to csv	Results from sensitivity analysis are exported to csv file.
Tables and graphs	Results illustrated in tables and graphs.

6 Conclusions

This deliverable represents the first step for implementing the open-source district cooling system planning tool developed within WP5 using Python programming language. The deliverable describes the purpose, scope, methods, results, main inputs, practical issues such as data structures/storage and GUI design to act as a guideline for the following task 5.2 planning tool implementation.

As a starting point for the effort, investigated systems are specified. These systems include both the district cooling system as well as building and space specific cooling systems that work as reference systems, i.e. represent a point of comparison for district cooling. Defining the components within the systems to be investigated by utilising user input and given default values in the first step of using the tool. The components or elements in the system definition can be categorised into five groups; resources, energy supply, cooling production, distribution and consumption. These categories are used in all analysis methods, input data and implementation.

The general approach in the analysis is to divide it in three separate, but interlinked parts; energy, economic and environmental analysis.

Energy analysis finds out how the specified system is operated and what is its primary energy consumption. The results is a product of an optimisation model generated using the information on system definition, and thus the energy analysis is actually a techno-economic analysis as prices of the commodities used (e.g. electricity) is taken into account. The modelling library used for the optimisation model is Oemof (“Open Energy System Modelling Framework”). The results of the optimisation are further utilised in economic and environmental analysis.

In economic analysis, the related investment costs are taken into account and the profitability or accumulated costs of the system are calculated over a specified life time.

The environmental analysis in the planning tool focuses on climate impacts of the district cooling systems in comparison to alternative cooling systems. The climate impact assessment will follow the framework of life cycle assessment (LCA). Thus, the LCA will provide information on potential emission savings achieved with the district cooling systems. In addition, it helps the user to recognise the most emission intensive components and functions of the system being studied, and thus enable efficient emission reduction measures. As LCA concentrates on all the inflows and outflows of substances it also reduces the risk of problem shifting, i.e. situations where an improvement in one part of the life cycle leads to weakening in another part.

Combining the results of the different analysis phases, combination indicators such as price of cooling or comparative indicators such as costs of emission reduction can be calculated. The planning tool will also include functionalities for performing a sensitivity analysis for each of the different analysis types.

Program implementation in Python will take advantage of object-oriented programming for data structures and storage. The predefined input data will be stored in .csv files.

Graphic user interface (GUI) of the planning tool is used to manage model data and structure and pass these values into optimization module of the tool, and also import result data from optimization in order to form easy to read result summary. GIS tool of GUI is utilized in forming simple but functional network of cooling system based on map file from the analysed area. GUI is constructed by using PySide library. GUI consists of 5 functional tabs: Analysis, GIS Tool, Parameters, Results and Sensitivity Analysis.