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D 4.2
Common monitoring methodology and data structure

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Revision History

Date	Partner	Ver.
2014-02-11	Preliminary draft uploaded on the sharepoint (new demonstrators)	1
2014-02-28	Final draft including the existing demonstrators	2
2014-03-18	Final version after second round of comments from partners responsible of the demonstrators	3

celsius smart cities

1. Introduction

The Celsius project aims at developing, optimizing and promoting efficient decentralized heating and cooling systems in cities by consistently contributing to the reduction of CO_2 emission and of primary energy consumption.
The project involves five different cities (Gothenburg, Cologne, Genoa, London and Rotterdam) and foresees the realization and monitoring of 10 new demonstrators covering different efficient technologies, systems and practices: development of ICT tools for the optimization of the energy management, innovative solutions for storage and load control, development of smart grids to increase the use of waste and renewable energy sources, development of innovative approaches for integrating energy centres to the grid, expansion of existing district heating/cooling networks.
Besides the new demonstrators that will be realized and operated during the Celsius project, operational existing demonstrators in the five cities are also part of the project aimed at covering a wide range of state-of-the-art demonstrators belonging to different categories for increasing the potential of replicability of the most efficient smart solutions in suitable contexts.

A list of new and existing demonstrators with the specific ID code is reported in the tables below:

Demo ID.	City	Demonstrator's Short Description
GO1	Gothenburg	Short term Storage
GO2	Gothenburg	District heating to white goods
GO3	Gothenburg	District heating to ships
RO1	Rotterdam	The heat hub
RO2	Rotterdam	Industrial ecology
LO1	London	Active network management and demand response
LO2	London	Capture of identified sources and waste heat and integration of thermal store
LO3	London	Extension of Bunhill "seed" heating system
CO1	Cologne	Heat recovery from sewage water (school buildings)
GE1	Genoa	Energy recovery from the natural gas distribution network

Table 1- New demonstrators in the Celsius project

Demo ID	City	Demonstrator's Short Description
12COe	Cologne	Biogas residential heating stammheim
28COe	Cologne	KlimaKreis -Koln funding local EE-initiatives
6COe	Cologne	Geothermal heating
36GOe	Gothenburg	Total production and distribution system
19GOe	Gothenburg	Absorption cooling
29GOe	Gothenburg	Climate Agreement
11GOe	Gothenburg	Cooling by river water
7GOe	Gothenburg	Industrial waste recovery
2GOe	Gothenburg	Integration with other municipalities
8GOe	Gothenburg	Recovery of heat waste incinerator
9GOe	Gothenburg	Biofuel CHP
20GOe	Gothenburg	Solar heat by DH system
17ROe	Rotterdam	Cooling by river water
5ROe, 14ROe	Rotterdam	Vertical city

Table 2-Existing demonstrators in the Celsius project

The following deliverable was developed in the framework of the WP4 which aims to identify methodologies and protocols that will be used for measurements, monitoring and evaluation of the demonstrators included in the framework of the Celsius project. In particular, the present document has been developed within the task 4.2 “Measurement and monitoring protocols”, which is focused on two main issues:

- Definition of a common methodology for measurement/monitoring and of a common data structure among the different demonstrators;
- Definition of a detailed metering/monitoring protocol for each demonstrator.

According to the aims described above, the document has been divided into two different parts:

- The first part is focused on the definition of a common monitoring methodology applied in the framework of the Celsius project, by taking into account both technical and social aspects of the monitoring. A common data structure has been elaborated in order to collect monitored data during the operation of the demonstrators;
- The second part is demo-specific and reports the most relevant energetic and non-energetic parameters to be measured, recorded and elaborated for each demonstrator during the operation. The elaboration of monitored data will be of crucial importance for the calculation of specific KPIs for each demonstrator, in order to compare social, economic, environmental and energetic performances of the demonstrator with the business as usual situation (i.e., baseline).

2. Common monitoring methodology

Since the Celsius project aims to be a corner stone in the large scale deployment of smart cities, demonstrators' monitoring is essential in evaluating the transfer and replication potential in different European regions.

Therefore, a common monitoring methodology applicable to different demonstrators has been set-up following a common approach for the evaluation of demo performances in view of potential future replicability of the projects in other contexts.

A schematic representation of the followed common monitoring methodology has been reported in Figure 2.1.

In particular the followed approach has included the development of two parallel activities along the life-cycle of each demo project:

- Monitoring of the **progress in the design and realization of the new demonstrators**, by identifying possible bottlenecks/barriers and by sharing with demo responsible partners strategies to overcome them in view of the start-up phase. A detailed report of this activity and of the progress of each demonstrator realization is reported in the deliverable 4.3 "Progress and achievements on each demonstrator and analysing causes for deviation" (M12).
- Monitoring the **operating performance both of new and existing demonstrators**; this activity has foreseen a preliminary step focused on the identification of specific key-parameters to be monitored in order to evaluate the demo performances from an energetic, economic, social and environmental point of view. Based on the defined KPIs (reported in the deliverable 4.1 "Report on KPIs values"), a list of specific energetic and non-energetic parameters has been identified for each demonstrator.

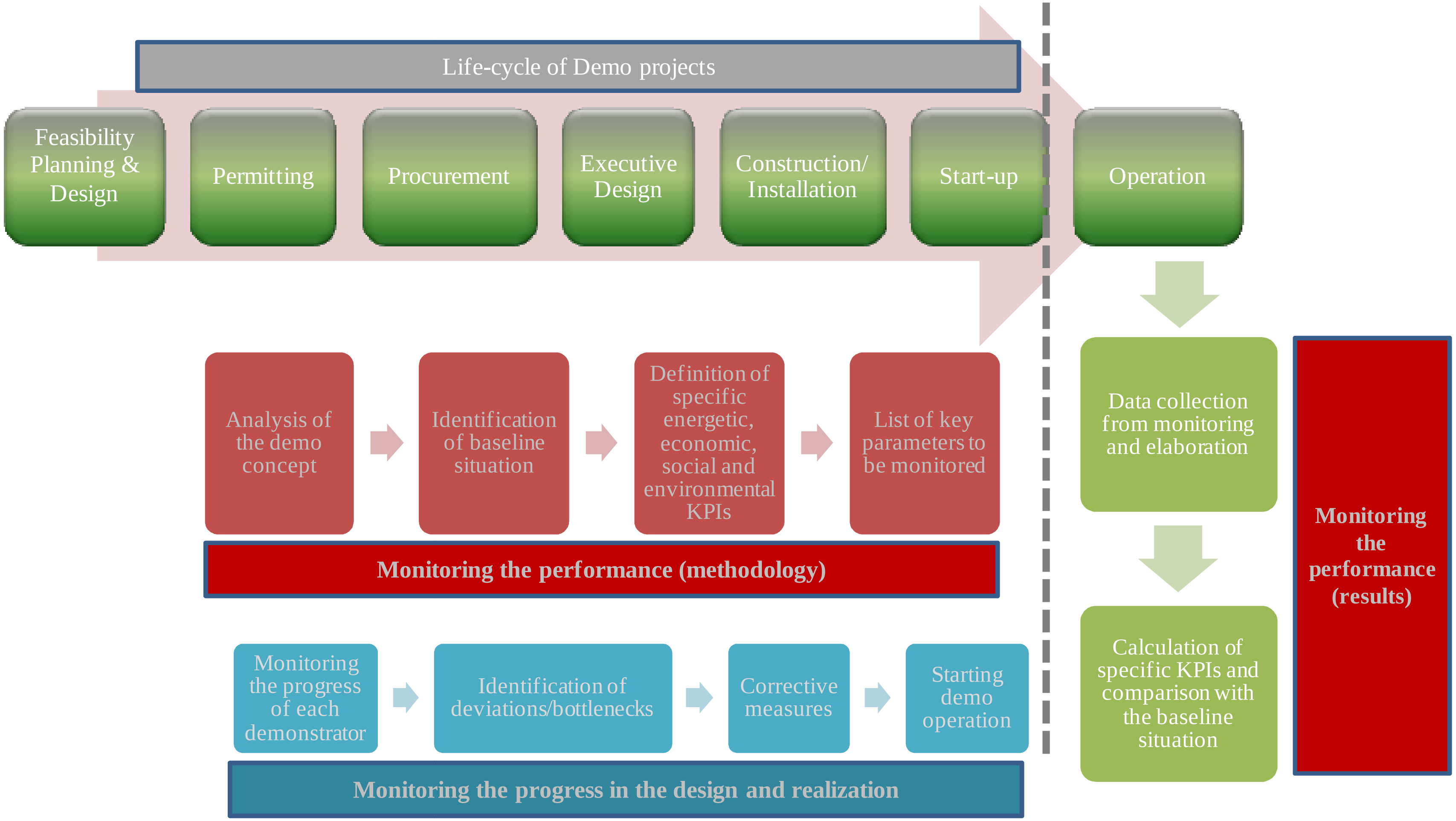

Figure 1 *Common monitoring methodology followed in the Celsius project*

2.1.1 Monitoring of progress in the design and realization of the demonstrators: methodology

With regards to the monitoring of the construction and operation progress, a specific template for reporting progress towards the realization phase has been implemented. The aim of this template is to identify for each phase of the demo realization process possible bottlenecks/barriers and to share with demo responsible partners strategies for their overcoming.

The monitoring methodology proposed for demos' progress monitoring during realization phase foresees that the developed template shall be filled in by each demo's responsible once every six months, thus allowing D'Appolonia team in charge of monitoring activities to collect and process the data. A detailed report of this activity and of the progress of each demo project will be reported in the deliverable 4.3 "Progress and achievements on each demonstrator and analysing causes for deviation" (M12). This deliverable will be progressively updated, with a six months frequency (in order to take track of the demonstrators' realization process.

The adopted common methodology for demo progress monitoring is articulated in different steps as presented in the following list:

- Identification of common project phases in which the realization process can be split up. The identified phases and the related definitions are listed below:
    - *Feasibility phase:* this phase is based on the examination of the project concept from different perspectives and considering different technical solutions in order to identify the design of the solution that best fits the mapped demand and the investors' requirements. This phase ends up with the availability of the business plan which is the tool on which the GO/NO GO decision for the investment to be made is taken;
    - *Planning and design phase:* on the basis of the conclusion of the feasibility phase, the detailed design of the solution to be adopted is carried out.
    - *Permitting phase:* this phase includes all the authorization and permitting procedures that shall be completed in order to allow construction/installation phase's starting;
    - *Area Preparation/Procurement phase:* this phase includes all the activities required for the site preparation necessary for completing the project and for the acquisition of the main equipment;
    - *Installation/Construction phase:* this phase corresponds to the effective Demonstrator's realization phase;
    - *Commissioning/Start up phase:* this phase is the final step before Demonstrator's production runs;
    - *Production/Operation phase:* this phase corresponds to the steady state of the Demonstrator.

- Analysis of the progress of each project phase in accordance to the time scheduling defined in the Description of Work (Annex I, Grant Agreement);

- Identification of possible delays and deviations from the original scheduled plan and detailed analysis of the related causes. The information gathered through this analysis will be extremely relevant in order to define criticalities deriving from the application of each innovative technology in the specific contexts in which they have been developed. This phase will result into the identification of a series of lessons learnt, aimed at increasing the potential for replication of the developed projects in the future;

- Investigation of deviation's impact on the other project phases in order to have a general overview about how delays/deviations in one project phase may affect the timeline scheduled for the following project phases;

- Suggestions for corrective actions/contingency plans to be adopted for reducing delays and guaranteeing the successful implementation of the project.

2.1.2 *Monitoring the performance (methodology)*

Regarding the monitoring methodology which will be implemented for the evaluation of the performance of each demonstrator, the following necessary working phases have been identified:

- Analysis of the demo concept: each demonstrator included in the Celsius project has its own specificity both in terms of technologies/smart solution which will be implemented and in terms of final end-users benefitting of the future operation of the demonstrator. In light of this, a specific case-by-case analysis taking into account both aspects has been performed. In particular, the following data/information are of primary importance for an in-depth analysis of the demo concept: background situation, objective of the demonstrator, technical solution, simplified layout of the process/flow diagram, investment costs, identification of the involved stakeholders and end-users and indications on the management model;
- Identification of the baseline situation: the business as usual situation has been identified for each demonstrator, aimed at defining a reference scenario to which compare the situation after the implementation of the innovative smart solution developed and operated in the framework of the Celsius project. Baseline situation corresponds to the natural prosecution in the future of the situation prior to the implementation of the demonstrator and it will be inferred by collecting data from energy demand and use from the same site before the installation and operation of the demonstrators or by similar contexts where the heating/cooling demand is managed in a conventional way;
- Definition of specific and general KPIs: relevant specific performance indicators have been identified for each demonstrator in accordance with its main objective and foreseen impact by taking into account energetic, economic, social and environmental aspects. A detailed description of the identified KPIs has been reported in the specific deliverable 4.1 “Report on KPI values”;
- List of key parameters to be monitored: in accordance with the defined specific KPIs, a list of energetic and non-energetic key-parameters to be measured and recorded during the operation has been identified for the new demonstrators and shared with each demo responsible partner. Concerning the existing demonstrators which are already in operation, a two-way communication with demo responsible partners, as necessary intermediary for the collection of information, has been established in order to select only those parameters which will be relevant for estimating the most significant KPIs in accordance with the main objectives of the Celsius project.

  A common template for data collection from monitoring has been set-up in order to uniform data variable names and facilitate the subsequent elaboration phase;
- Data collection and elaboration from monitoring: following the provided indications and common template, monitoring data from the different demonstrators will be periodically collected and analyzed, in order to trace the trend of the different parameters during time;
- Evaluation of the performance: data from monitoring will constitute the basis for the periodical calculation of the defined specific KPIs, in order to evaluate the performances trend during time. Moreover, specific KPI values will include comparison with the baseline situation in order to measure the efficiency and impact of the new solution at energetic, economic, social and environmental point level.

2.1.2.1 Common data structure

The quantitative aspects of monitoring take into account all the parameters of relevant importance which are worth to be measured and recorded during the operation of the demonstrators. The monitoring of the demonstrator consists of two different phases:

- Phase A (definition of a preliminary monitoring plan);
- Phase B (elaboration of data monitored during the operation).

Phase A

In order to define a plan for the monitoring of each demonstrator, a common template has been set-up in order to identify the relevant categories of information to be collected during the operation of the demonstrators.

In particular, as reported in the template in Figure 2, for each identified parameter the following information are necessary:

- *Typology of data to be measured and recorded*: the main physical parameters which will be measured during the monitoring are: temperatures, thermal energy, electric energy consumptions, water/ gas flows, etc... Apart from energetic parameters, a list of non-energetic parameters not related to energy efficiency (i.e., tariffs, environmental emissions, etc..), have been also identified for each demonstrator;
- *Data variable name*: each parameter will have a specific identification name in order to avoid possible misunderstandings coming from the monitoring of similar physical measurements performed in different points and possible mistakes in the monitoring phase due to the large amount of data to be elaborated. In particular the following nomenclature has been suggested according to the identified macro-categories of possible measurements:
    - *Q=thermal energy;*
    - *C=electric energy consumption;*
    - *P=electric energy generation;*
    - *G,V=mass, volume flow rate;*
    - *T, F= tariff, fees;*
    - *Te=temperatures;*
    - *E= pollutant emission factors;*
  - *Units of measurement*;
  - *Location of measurement*: in many cases, different sites (production site, distribution site, end-user site) are involved in the same demonstrator, each having specific parameters to be measured. In light of this, for each parameter, the location of measurement must be indicated, possibly by reporting distances among the different measurement locations;
  - *Monitoring equipment:* for each parameter, the equipment used for monitoring will be indicated once the demonstrator will be in operation. In particular, it will be recommendable to include information on data accuracy associated to each implemented monitoring equipment, thus allowing the estimation of uncertainty associated to measurements;
  - *Recording frequency:* considering the specific purpose of the demonstrator and the associated KPIs to be evaluated from monitoring, each parameter will have a specific recording frequency (hourly, daily, monthly, ...) which must be indicated in the template;

- *Comments:* all relevant comments must be reported in order to keep track of unusual situations, with particular reference to possible failures or eventual periodic calibration tests of monitoring equipment.

DATA TYPOLOGY	VARIABLE NAME	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENT	RECORDING FREQUENCY	MONITORING EQUIPMENT AND DATA ACCURACY	COMMENTS
Parameter 1 *(e.g.: indoor temperature)*						
Parameter 2						
Parameter 3						
….						
Parameter *n*						

Table 3 Common data structure

Phase B

Raw data from measurements of the new demonstrators, performed according to the protocol agreed in the monitoring plan indicated in phase A will be electronically stored by each demo responsible partner and sent to D’Appolonia team for the elaboration phase with a six month frequency in order to trace the trend during time for each monitored parameter and calculate the identified performance indicators (following the methodology of calculation indicated in the correspondent deliverable 4.1 “Report on KPIs”).

Results of data elaboration will be shared and agreed with demo responsible partners and then included in the progressive deliverable 4.3 aimed at evaluating the main achievements on each demonstrator.

Concerning the existing demonstrators, data stored from monitoring will be collected and analyzed once for a specific year in order to calculate the KPIs values and provide valuable inputs to the Celsius toolbox aimed at supporting any city in Europe in maximizing the efficient utilization of its energy resources in an integrated way.

3. Specific monitoring protocols: new demonstrators

Following the common template in Figure 2, a preliminary monitoring plan was elaborated for each demonstrator and shared with each demo responsible partner.
Concerning the new demonstrators, the actual implementation of the suggested measurements will be subject to a cost-benefit evaluation by partners who will sustain the cost for the installation of the necessary equipment. As a consequence, demo responsible partners will evaluate, when the time is mature enough with the demo implementation schedule, the real measurements to be implemented.
In the sub-paragraphs below, the analysis of each new demonstrator realized and operated in the framework of the Celsius project is reported by including a description of the implemented technology, a simplified layout of the technical solution, the list of relevant energetic and non-energetic monitoring parameters and a summary table containing indications on frequency and location of measurements, according to the common template reported in table 3.

3.1.1 Genoa demonstrator GE1

3.1.1.1 Demo Concept

The main objective of Genoa's demonstrator is to exploit the natural gas pressure drop at a main gas distribution substation for generating electric energy. This will be possible through the installation of an expansion turbine; a new gas-fired CHP plant is foreseen to provide the heat needed by gas expansion and to produce additional electric energy.
The industrial area where the demonstrator will be implemented hosts the natural gas distribution facilities, where the gas pressure is reduced from the high pressure transmission levels (24 bar) of the national gas network to a reduced pressure (5 bar) through a standard lamination process. With the implementation of the new demonstrator, a large fraction of the incoming gas will be driven in the new system instead of passing the existing lamination valves. In the new system, gas will be pre-heated by means of heat coming from the gas-fired CHP plant, then it will be expanded in the turbo-expander which will generate electric energy. The CHP will produce additional electric energy and it will produce thermal energy not only for the gas pre-heating in the turbo-expander, but also for a small district heating network serving several buildings inside and outside the industrial park, as for example a fire-fighter's station.
The demonstrator will be implemented and operated by Genova Reti Gas (the Distributor Operator for the gas network of Genoa City) and it is constituted of the following main equipments:

- **Turbo-expander** for natural gas (along with all its auxiliary components), which will allow recovering the mechanical energy inherent in the pressurized natural gas (currently wasted within a standard lamination process) to generate electric energy that will be distributed to the district;
- **Gas-fired CHP plant** which will provide heat to the gas-heating necessary before the expansion in turbine and service the heating network of the surrounding Gavette district;
- **Remote control** of gas consumption, which will allow the rationalisation of consumption patterns within the industrial park and the district.

The list of parameters to be monitored during the operation of the demonstrator have been identified and shared with the demo responsible partner, according to the common template described in paragraph 2.1.1.

A simplified layout of the process related to this Demonstrator is reported in the figure below:

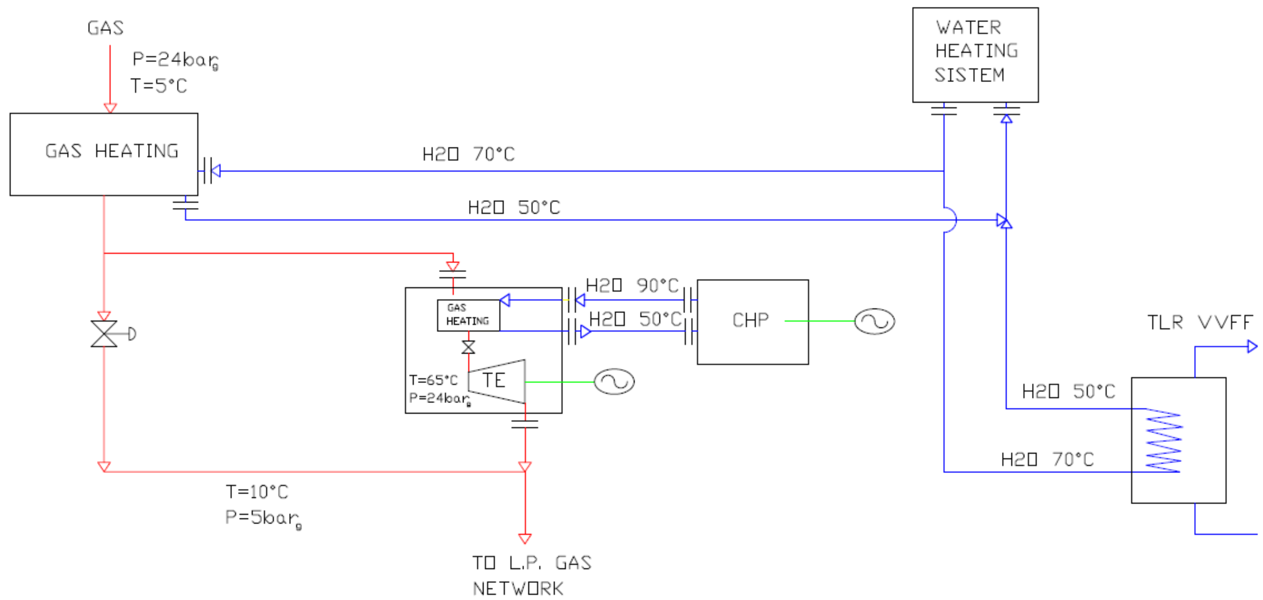

Figure 2 *Simplified layout (GE1)*

3.1.1.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Natural gas flow - Nm^3/h:
    - Burned at each boiler;
    - Burned at the co-generator;
    - Through the turbo-expander;
    - Through the lamination valves;
- Thermal energy (as indirect measure obtained from water flow rate, inlet and outlet water temperature) – *kWht*:
    - At each boiler;
    - At the CHP;
    - At the turbo-expander pre-heating and/or post-heating sections;
    - At the lamination battery;
    - At each district heating branch;
    - At each building substation;
- Thermal energy consumption in one building of Genove Reti Gas (as indirect measure obtained from water flow rate, inlet and outlet water temperature), coupled with a room by room temperature control system;
- Electric active (*kWhe*) and apparent (*kVArh*) energy:
    - Gross electric energy at the turbo-expander;
    - Gross electric energy at the CHP;
    - Electric energy consumption at the substation;
    - Electric energy self-consumption of turbo-expander;
    - Electric energy self-consumption of CHP;
    - Electric energy consumption at the main consumption counter;

- Sample measurement of temperature at stacks of co-generator and of boilers-°*C*;
- External ambient temperature- °*C*.

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below:

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Natural gas flow at each boiler	$G_{B,i}$	Nm^3/h	At each boiler (i)	Hourly	-
Natural gas flow at the cogenerator	G_{CHP}	Nm^3/h	At the cogenerator	Hourly	-
Natural gas flow at the turbo-expander	G_{TE}	Nm^3/h	At the turbo-expander	Hourly	-
Natural gas flow at the lamination valves	G_{LV}	Nm^3/h	At the lamination valves	Hourly	-
Thermal energy produced by each boiler	$Q_{B,i}$	kWht	At each boiler (i)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy produced by the cogenerator	Q_{CHP}	kWht	At the cogenerator	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy needed by the turbo expander	Q_{TE}	kWht	At the turbo-expander	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy at the lamination valves	Q_{LV}	kWht	At the lamination valves	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy provided to the district heating	$Q_{DH,j}$	kWht	At each district heating branch (j)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy provided to the building substation	$Q_{BS,\ k}$	kWht	At each building substation (k)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)

Thermal energy at each room	$Q_{R,\ h}$	kWht	At each room of one building served by the new system (h)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Stack temperature at CHP	Te_{CHP}	°C	At the stack of cogenerator	Sample measurements	-
Stack temperature at boilers	$Te_{B,i}$	°C	At the stack of boilers (i)	Sample measurements	-
External ambient temperature	Text	°C	Outdoor, in the same area of end-users	Hourly	-
Gross electric active (and apparent) energy at turbo-expander	P_{TE}	kWhe (kVArh)	At the turbo-expander	Hourly (if possible to be intensified during specific events/diseases)	-
Gross electric active (and apparent) energy at co-generator	P_{CHP}	kWhe (kVArh)	At the cogenerator	Hourly (if possible to be intensified during specific events/diseases)	-
Electric active (and apparent) energy for self-consumption at the substations	$C_{BS,k}$	kWhe (kVAhr)	At each building substation (k)	Hourly (if possible to be intensified during specific events/diseases)	-
Electric active (and apparent) energy for self-consumption at the turbo-expander	C_{TE}	kWhe (kVArh)	At the turbo-expander	Hourly (if possible to be intensified during specific events/diseases)	-
Electric active (and apparent) power self-consumption at the cogenerator	C_{CHP}	kWh (kVArh)	At the cogenerator	Hourly (if possible to be intensified during specific events/diseases)	-

Table 4 - Technical monitoring parameters (GE1)

Apart from the energetic parameters, aimed at evaluating the energy efficiency of the implemented solution for the GE1 demonstrator, a list of non energetic parameters (i.e., tariffs) to be monitored and recorded possibly on a monthly basis will be useful for the evaluation of the performance of the demonstrator. In particular, the following tariffs with details on the cost structure (as for example taxation rate, differentiation on the basis of the time slot, etc..) have been identified:

- Tariff for natural gas provision paid by the network manager- *€/Nm*^{3}.
- Tariff for the electric energy consumption paid by the network manager- *€/kWh*$_e$.
- Tariff for natural gas consumption paid by the end-user- *€/Nm*^{3}.
- Selling price of electric energy produced by the network manager and sold to new end-users (if any)- *€/kWh*$_e$.
- Tariff for thermal energy consumption paid by end-users connected to the new heating system - *€/kWh*$_t$.
- Maintenance cost of the CHP sustained by the district heating network manager- €.
- Maintenance cost of the TE sustained by the district heating network manager- €.

A summary table with the list of the identified economic parameters is reported in the table below:

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Tariff for natural gas consumption paid by the network manager	$T_{gas, DHM}$	€/Nm^3	Monthly
Tariff for electric energy consumption paid by the network manager	$T_{el, DHM}$	€/kWhe	Monthly
Tariff for natural gas consumption paid by the end-user	$T_{gas, end-users}$	€/Nm^3	Monthly
Selling price of electric energy produced by the network manager and sold to new end-users (if any)	$T_{el, end-user}$	€/kWhe	Monthly
Tariff for thermal energy consumption paid by end-users connected to the new heating system	$T_{th, end-user}$	€/kWht	Monthly
Maintenance cost of the CHP for the district heating network manager	M_{CHP}	€	Every six months
Maintenance cost of the TE for the district heating network manager	M_{TE}	€	Every six months

Table 5 - Economic monitoring parameters (GE1)

3.1.2 *Gothenburg Demonstrator GO1*

3.1.2.1 Demo Concept

The idea underlying the GO1 Demonstrator ("Using building as short term storage") is to exploit the thermal capacity of apartments' structural elements (e.g.: floors, ceilings and walls) for heat storage and enhanced heat control purposes. The mentioned elements will be "loaded" with energy during low consumption hours (and the indoor temperature will slightly increase); as a consequence there will be a minor temperature increase during night time, when the heat demand is low, and a minor decrease during demand peak hour, i.e. in the morning. The inhabitants should not notice these temperature changes and the implementation of this Demonstrator will allow keeping the heat production at a lower level during peak hours. In total 900 flats will be connected, corresponding to approximately 75.000 m^2 of living area.
A simplified layout of the GO1 demonstrator is reported in the figure below:

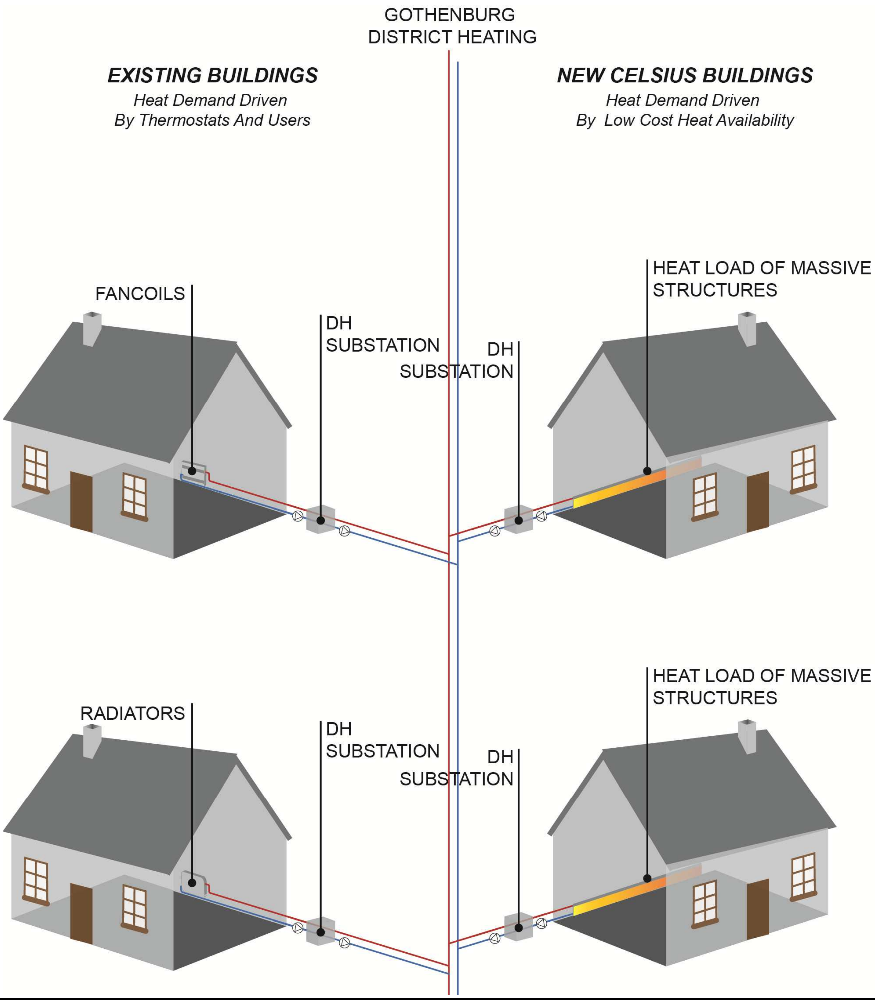

Figure 3 *Simplified layout (GO1)*

3.1.2.2 Parameters

The most important specific technical parameters to be monitored and recorded for GO1 demonstrator are listed below:

- Internal temperatures at apartment level (4 different apartments will be monitored as reference examples)–*°C*;
- Thermal energy delivered to the building – *kWht*;
- Electric energy consumption of control equipment – *kWhe*;
- External temperature –*°C*;
- Thermal energy loss in the network- *kWht*;
- District heating production mix – *MWht and composition %*;
- Electric energy consumption in distribution network pumps– *kWhe.*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recoding frequency and possible comments, is reported below.
Moreover, a list of non-energetic parameters to be monitored and recorded have been identified in order to collect information during the operation of the demonstrator which will be of crucial importance for the evaluation of the generic and specific KPIs identified in the framework of Celsius project.
In particular, the following parameters have been identified, discussed and shared with the demo responsible partners to be monitored during the operation of the demonstrator:

- Tariff for thermal energy consumption paid by end-users connected to the new system- *€/kWht*;
- Tariff for electric energy consumption paid by the district network manager-*€/kWhe*.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Internal temperature	$Te_{in,}$ 1	°C	At apartment level	Hourly	-
Internal temperature	$Te_{in,}$ 2	°C	At apartment level	Hourly	-
Internal temperature	$Te_{in,}$ 3	°C	At apartment level	Hourly	-
Internal temperature	$Te_{in,}$ 4	°C	At apartment level	Hourly	-
Thermal energy delivered to the building	$Q_{b,i}$	kWht	At each building (i)	Hourly or each 15 minutes preferable if possible	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Electric energy consumption of control equipment	C_i	kWhe	At each building (i)	Hourly	-
External temperature	Te_{ext}	°C	Outdoor in the same building area	Hourly	-
District heating production mix	$Q_{mix, DH}$	MWht and % composition	At district heating	Monthly	-
Thermal energy loss in the network	$Q_{loss, DH}$	kWht	At district heating	Monthly	-
consumption in distribution network pumps	C_{DH}	kWhe	At district heating	Monthly	-

Table 6 - Technical monitoring parameters (GO1)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Tariff for thermal energy consumption paid by end-users connected to the new system	$T_{th,\ end\text{-}user}$	€/kWht	Monthly
Tariff for electric energy consumption paid by the heat network manager	$T_{el,\ DHM}$	€/kWhe	Monthly

Table 5 - Non-Energetic monitoring parameters (GO1)

3.1.3 Gothenburg Demonstrator GO2

3.1.3.1 Demo Concept

The overall objective of GO2 Demonstrator ("District heating to white goods") is to install, operate and monitor performances of white goods (e.g. dishwashers, washing machines and dryers) able to use district heating hot water for heating demand instead of currently dominating electric resistances and using electric energy only for motors and in rare situations of high peak heat demand. The implementation of the Demonstrator foresees the verification of both the operation of the machines themselves and their installation in the flats. This will be done by installing totally 300 machines (100 dish washers, 100 washing machines and 100 dryers) in laundry rooms of buildings in the residential area Kvillebäcken in Gothenburg.

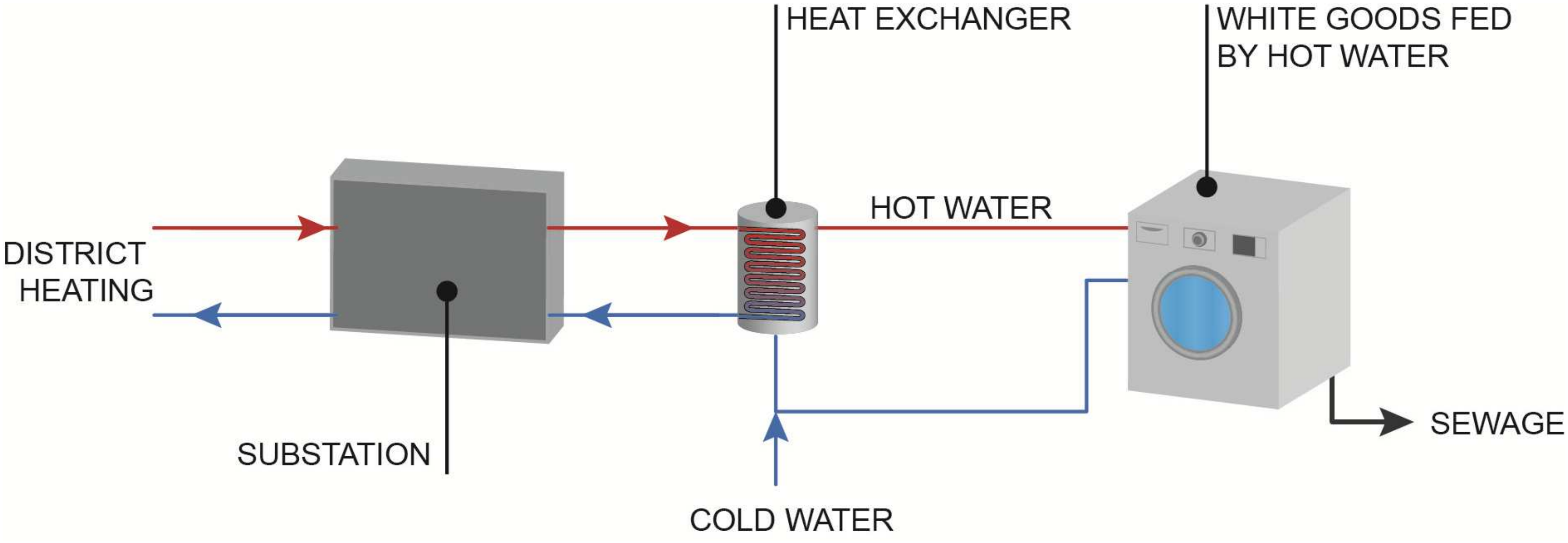

Figure 4: *GO2 simplified layout*

3.1.3.2 Parameters

The most important energetic monitoring parameters for GO2 demonstrator are listed below:

- Thermal energy delivered to white goods- *kWht*;
- Supply and return temperatures of heating water –°*C*;
- Electric energy consumption of white goods – *kWhe*;
- District heating production mix- *MWht and % composition*;
- Thermal energy loss in the network- %;
- Electric energy use in the distribution network pumps- *kWhe.*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recoding frequency and possible comments, is reported below.

A list of non-energetic parameters to be monitored and recorded have been identified in order to collect information during the operation of the demonstrator which will be of crucial importance for the evaluation of the generic and specific KPIs identified in the framework of Celsius project.

In particular, the following parameters have been identified:

- Number of washes;
- Time for a washing/ drying cycle- *minutes*;
- Tariff for electric energy consumption paid by the end-user - €/*kWhe*;
- Tariff for thermal energy consumption paid by the end-user - €/*kWht.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Thermal energy delivered to white goods	$Q_{wg,i}$	kWht	At each machine (i)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Supply temperature	$Te_{in,j}$	°C	At each laundry room (j)	Hourly	-
Return temperature	$Te_{out,j}$	°C	At each laundry room (j)	Hourly	-
Electric energy use of white goods	$C_{wg,\ j}$	kWhe	At each laundry room (j)	Hourly	-
District heating production mix	$Q_{mix,\ DH}$	MWh and % distribution of each thermal source	At the district heating branch	Monthly	-
Thermal energy loss in the network	$Q_{loss,\ DH}$	%	At the district heating branch	Monthly	-
Electric energy use in the distribution network pumps	C_{DH}	kWhe	At the district heating branch	Monthly	-

Table 7 –Energetic monitoring parameters (GO2)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Number of washes	$N_{w,\ j}$	-	Each laundry room (j)	-	Can be calculated from energy measurements
Time for a washing cycle	tw	Minutes	Each laundry room (j)	Average value	-
Time for a drying cycle	td	Minutes	Each laundry room (j)	Average value	-
Tariff for electric energy consumption paid by the end-users	$T_{el,\ end\text{-}user}$	€/kWhe	-	Monthly	-
Tariff for thermal energy consumption paid by end-users	$T_{th,\ end\text{-}user}$	€/kWht	-	Monthly	-

Table 8 - Non-Energetic monitoring parameters (GO2)

3.1.4 Gothenburg Demonstrator GO3

3.1.4.1 Demo Concept

The overall objective of GO3 Demonstrator ("District heating to ships") is to use district heating to heat ships at quay in Gothenburg harbour. Traditionally, when a ship is at quay, it still needs to run electrical generators and heating equipment, normally consuming bunker oils for both purposes. In Gothenburg, there are already possibilities to connect ships at quay to the electrical grid, but heating equipment on board still needs to be used.

Within the implementation of the new Demonstrator, one ship will be connected to the district heating system from the city through a mobile tube in order to reduce the consumption of bunker oils in traditional boilers for heating purposes.

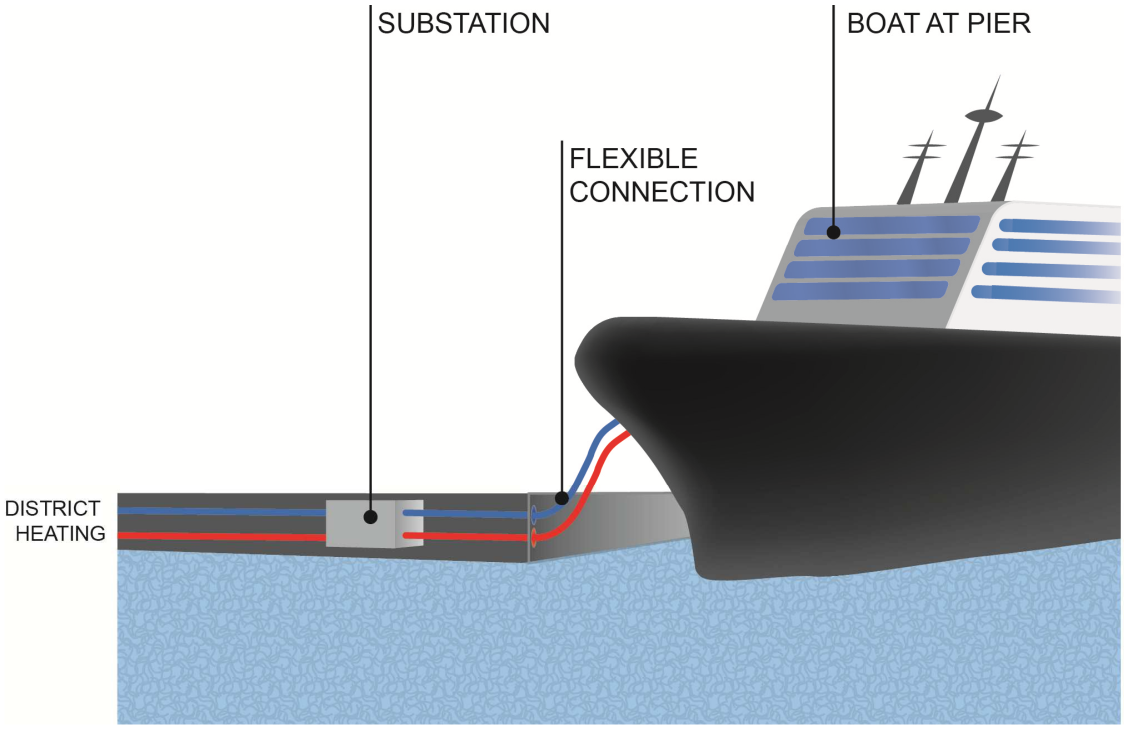

Figure 5: *GO3 simplified layout*

3.1.4.2 Parameters

The most important energetic monitoring parameters for GO3 demonstrator are listed below:

- Thermal energy delivered to ship from the city district heating system- *kWht*;
- Oil consumption for heating purposes at harbour *–lt*;
- Outdoor temperature – *°C*;
- District heating production mix- *MWht*;
- Thermal energy loss in the network- %;
- Electric energy use in the distribution network pumps- *kWhe.*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported in table 9.

A list of other significant parameters to be monitored and recorded have been identified in order to collect information during the operation of the demonstrator which will be of crucial importance for the evaluation of the generic and specific KPIs identified in the framework of Celsius project.

In particular, the following non-energetic monitoring parameters have been identified:

- Tariff for the electric energy consumption paid by the district heating network manager- $€/kWh_e$;
- Tariff for thermal energy consumption paid by the end-users connected to the new system - $€/kWh_t$;
- Cost for the maintenance of the new system- €;
- Cost of bunker oil- *€/kg.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Thermal energy delivered to ship from the district heating system	Q_{sh}	kWht	At ship	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Oil consumption for heating purposes in harbour	V_{oil}	lt	At ship	Yearly	-
Outdoor temperature	$Te_{,ext}$	°C	Outdoor, at quay	Hourly	-
District heating production mix	$Q_{mix, DH}$	MWht and % composition	At the district heating branch	Monthly	-
Heat loss in the network	$Q_{loss, DH}$	%	At the district heating branch	Monthly	-
Electric energy use in the distribution network pumps	C_{DH}	kWhe	At the district heating branch	Monthly	-

Table 9 - Technical monitoring parameters (GO3)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Tariff for the electric energy consumption paid by the district heating network manager	$T_{el, DHM}$	€/kWhe	Monthly
Tariff for thermal energy consumption paid by the end-users connected to the new system	$T_{th, end-user}$	€/kWht	Monthly
Cost of maintenance of the new system	M	€	Every six months
Cost of bunker oil for ship	T_{oil}	€/lt	Monthly if possible (estimation based on assumed price according to available data).

Table 10 – Non-Energetic monitoring parameters (GO3)

3.1.5 Cologne Demonstrator CO1

3.1.5.1 Demo Concept

The main objective of Cologne's Demonstrator is to recover the **waste heat coming from sewage water** and use it in decentralized local heating network by supplying thermal energy to local school buildings. In particular the project involves three different sites:

- *Nippes*: three different schools are located close to a pumping station of the sewage network. Part of the sewage at the station will be by-passed, and then fed to a heat exchanger. From there, heat will be transferred to a heat pump systems (3 heat pumps of 160 kW each) situated in the central boiler room in the Edith-Realschule for the base load supply to the three schools. Three new gas fired condensing boilers will be used for peak load;
- Mülheim: the Hölderlin Gymnasium is located close to a main pipe of the sewage network. The shape of the sewage pipe differs to the one in Porz/ Wahn. The heat exchanger will be installed on the bottom of the pipe. The heat pump will be placed in the heating room in the cellar of the Hölderlin Gymnasium. The peak demand will be supplied by a gas boiler.
- Porz/ Wahn: 2 schools are located close to each other, beside a main pipe of the sewage network. The heat exchanger will be installed on the bottom of the pipe. The water heated through this heat exchanger will flow to the heat pump in the central boiler room in the Otto-Lilienthal Realschule. The heat pump will supply base load heating and a condensing gas boiler will be used for peak load.

A simplified layout of the demonstrator is reported in the figure below:

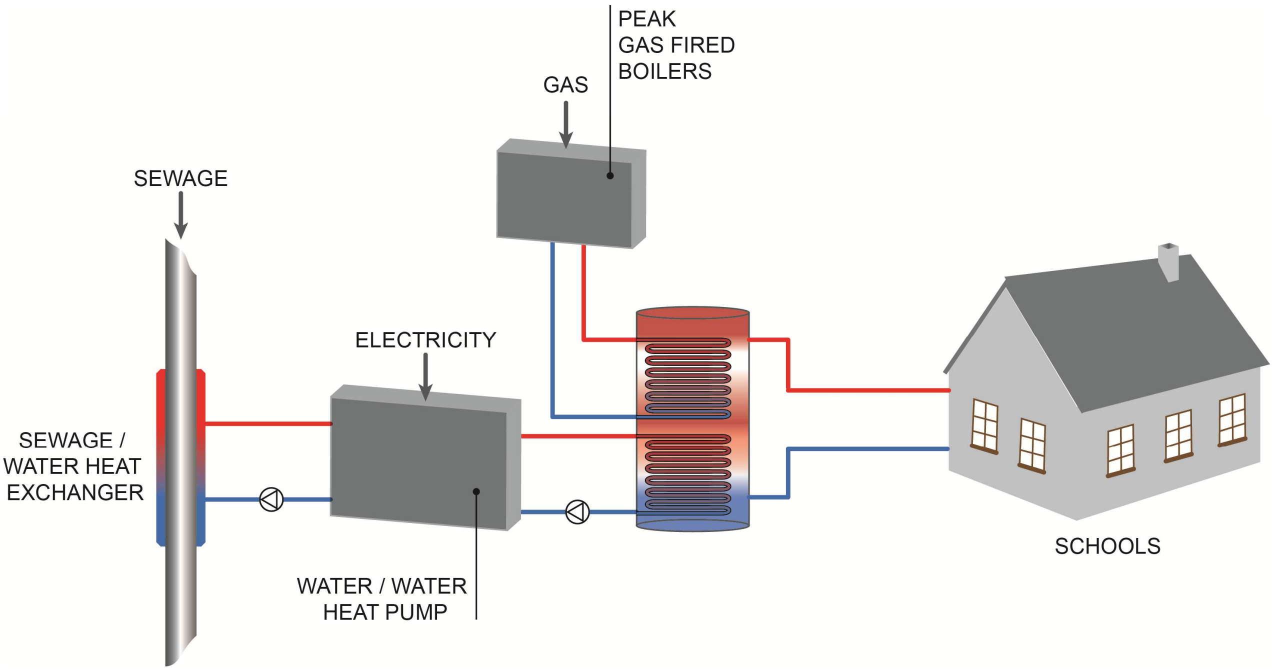

Figure 6- *Simplified layout (CO1)*

3.1.5.2 Parameters

Considering that the technical solution implemented in the three different sites is similar (i.e., heat pumps recovering waste heat from sewage water), parameters to be monitored and recorded will be the same for the different sites.
Nevertheless a continuous monitoring of the demonstrators at three locations is necessary, due to the different characteristics of waters used as sinks (with different degree of solids, viscosity, temperatures, etc...) implying different performances.
The identified energetic parameters to be monitored and recorded are listed below:

- Electric energy consumption of the heat pumping system- *kWhe:*
  - Used by the compressors;
  - Used for pumping systems;
  - Used for the internal units;
  - Used for the external heat exchanger;

  Peak demand (kW) per each consumption should also be recorded
- Electric energy consumption of the wastewater pumping system– *kWhe*;
  Also peak consumption (kW) should be considered.
- Average flow rate and temperatures of incoming and outgoing wastewater– *m^3/h and °C (the measurement of the flow rate is rather costly; demo responsible partner will examine how this can be solved in a reasonable cost-benefit ratio)*;
- Thermal energy (water flow rate, inlet and outlet water temperature)- *kWh* :
  - At the distribution mine;
  - At the heat pump;
  - Between the storage system and the distribution mine;
- Refrigerant liquid type, pressure (*bar*) and losses (*lt/year):*
  Heat pumps circuits are loaded usually with HFC gases, having high global warming potential. Their circuits have small losses requiring periodical recharge. The losses should be assessed annually through pressure measurements in the heat pump circuit and recharges should be measured. The register of these data should also keep control of the work fluid type.
- Gas consumption in peak boilers- *Nm^3/h.*

Other relevant non-energetic parameters identified for the case are listed below:

- Tariff for thermal energy consumption paid by end-users connected to the new system- *€/kWh_t*.
- Tariff for natural gas consumption paid by the end-user- *€/Nm^3*.
- Tariff for natural gas consumption paid by the heat network manager- *€/Nm^3*.
- Tariff for electric energy consumption paid by the network manager- *€/kWh_e*.
- Maintenance cost for the network manager- *€.*
- Exhausted gas flow rate (*Nm^3/h*) and polluting emission concentrations (CO_2, CO, NO_x, SO_x, PM, PM_{10}, $PM_{2.5}$- *mg/Nm^3*) by the peak load boilers serving the Celsius sub-project

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Electric energy consumption of the heat pumping system	$C_{hp, i}$	kWhe	At each heat pump system (i)	Hourly	-
Electric energy consumption of the wastewater pumping system	C_{wp}	kWhe	At wastewater pump	Hourly	-
Wastewater flow rate through the heat exchanger	V_w	Nm^3/h	At wastewater heat exchanger	Daily	The measurement of the flow rate is rather costly; demo responsible partner will examine how this can be solved in a reasonable cost-benefit ratio
Inlet wastewater temperature	$Te_{w,in}$	°C	At wastewater heat exchanger	Hourly	-
Outlet wastewater temperature	$Te_{w,out}$	°C	At wastewater heat exchanger	Hourly	-
Thermal energy at the heat pump	$Q_{hp,i}$	kWht	At each heat pump system (i)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy between the storage system and the distribution mine	$Q_{st\text{-}dist, j}$	kWht	At each storage system (j)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy at the distribution mine	$Q_{dist, m}$	kWht	At each distribution mine (m)	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Gas consumption	$G_{gas, k}$	Nm^3/h	At each peak boiler (k)	Hourly	-
Refrigerant losses	L_{ref}	lt/year	At each heat pump system (i)	Yearly	-

Table 11 –Energetic monitoring parameters (CO1)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Tariff for thermal energy consumption paid by end-users connected to the new system	$T_{th, end-user}$	€/kWht	Monthly
Tariff for natural gas consumption paid by end-users	$T_{gas, end-user}$	€/Nm^3	Monthly
Tariff for natural gas consumption paid by the heat network manager (DHM)	$T_{gas, DHM}$	€/Nm^3	Monthly
Tariff for electric energy consumption paid by the network manager (DHM)	$T_{el, DHM}$	€/kWhe	Monthly
Maintenance cost for the network manager	M	€	Every six months
Exhausted gas flow rate (Nm^3/h) and polluting emission concentrations (CO_2, CO, NO_x, SO_x, PM, PM_{10}, $PM_{2.5}$-mg/Nm^3) by the peak load boilers serving the Celsius sub-project	$G_{emission, k}$	Nm^3/h	According to national regulation for periodical control

Table 12 – Non-Energetic monitoring parameters (CO1)

3.1.6 London Demonstrator LO1

3.1.6.1 Demo Concept

The aim of LO1 Demonstrator ("Active Network Management and Demand Response") is to provide Demand Response (DR) to alleviate the electric network constraints and faults by means of incorporating CHP-generated electricity as an ancillary supply at times of network need.
At times of high network demand, the transformers in substations can reach loading levels outside of operational guidelines. While this is not necessarily dangerous, when a transformer has exceeded statutory limits it can lead to thermal and load faults. In both cases, the operation of the transformer will either automatically trip out or need to be temporarily suspended. The concept idea at the basis of LO1 Demonstrator is that, by providing a supplementary supply within the local network thanks to the smart management of an existing district-scale cogeneration system (which also feed a DH system), the load on the substation can be reduced.
Thus, UK Power Networks will be working with Islington Council who own the Combined Heat and Power unit (CHP) at Bunhill Energy Centre (BEC) to contract DR services as part of the CELSIUS project.
The events will be autonomously dispatched via a system developed by UK Power Networks and Smarter Grid Solutions (SGS). This Active Network Management (ANM) system will be capable of monitoring substation loads and dispatching DR events when the network is in need.
A simplified layout of the process related to this Demonstrator is reported in the figure below.

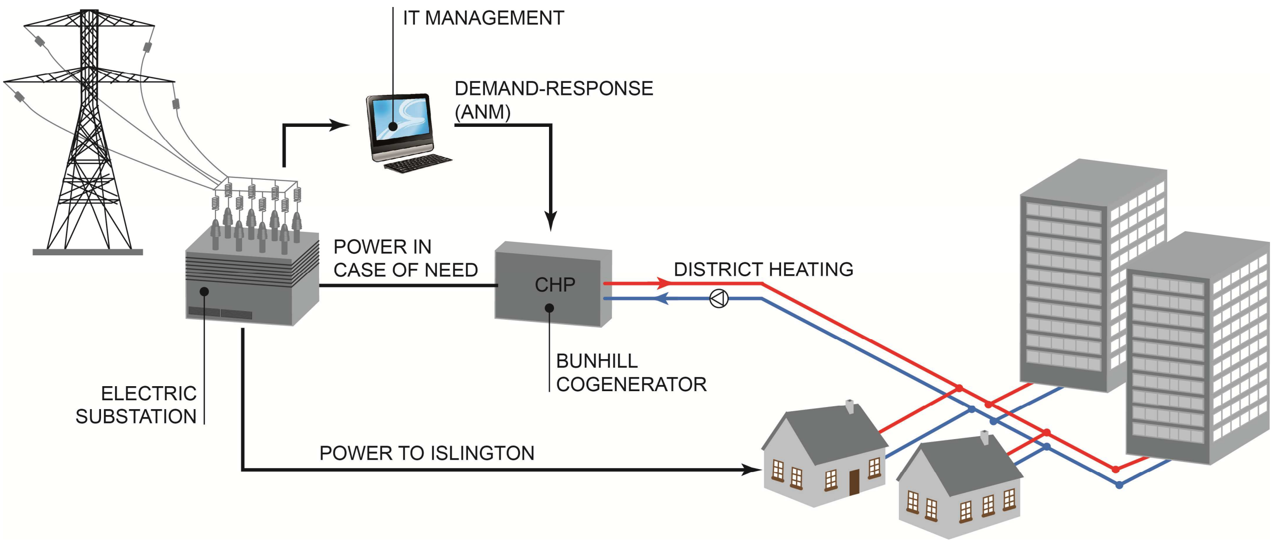

Figure 7- *Simplified layout (LO1)*

3.1.6.2 Parameters

The most important parameters to be monitored and recorded are divided among service quality parameters (continuous monitoring) and energy parameters (to be monitored during a specific event).
In order to clearly decouple LO1 project features from the normal operational routine of the co-generator, the main unit to define for the monitoring is **the event**, i.e. the single situation when the DR system requires the co-generator to support the electric substation.

The main parameters needed to define an event are:

- Date and time;
- Type (real/simulated);
- Previous conditions of the co-generator (normal operation, operation at partial load or standby);
- Request type (power increase, production anticipation or delay in case of DH operation);
- Event duration.

During each event the following technical parameters are recommended to be monitored:

- Use of natural gas at the co-generator (Nm^3);
- Electric energy produced (*kWhe)* during the event;
- Thermal energy produced and used in the DH (*kWht*) during the event;
- Thermal losses (*kWht*) during the event. We consider the difference between thermal energy produced during the event (and stored) and its subsequent use in a delayed time;
- Electric energy used (*kWhe*) to keep the co-generator ready to be used out of DH normal use (daily, weekly or monthly evaluation).

Non technical-parameters, related to the economic aspects deriving from the implementation of the DR system are also worth to be monitored and recorded during the event in order to evaluate the economic impact for the involved stakeholders.
The following non-energetic monitoring parameters have been identified:

- The fee guaranteed by the Distribution Network Operator (UKPN) to the co-generator manager (BEC) during the event (per each event), referred to as utilisation payments (to be confirmed)- *€/event*;
- The fines paid by UKPN to the industry regulator in the case of network outage - *€/each event*;
- The maintenance and operation extra-costs paid by BEC for the co-generator management to warrant its availability for fault management- €.

In terms of **service quality/grid stability/security of supply**, the main parameters to be continuously monitored and recorded are:

- At the substation on a minutely basis:
    - Real Power- *kW*;
    - Max Real Power- *kW*;
    - Real Power set point (thresholds)- *kW*;
    - Reactive Power- *kVAr*;
    - Reactive Power Set Point (thresholds)- *kVAr*;
    - Volts-*V*;
    - Power Factor (-1 to 1).
    - Max positive Power Factor (0 to 1)
    - Max negative Power Factor (-1 to 0)
    - Current- *A*;
    - Major fault indication (*I/O*);
    - Capacity available for ANM dispatch- *kW*;
- At the co-generator on a minutely basis:

- DR availability- *kW*;
- Real Power- *kW*;
- Voltage- *V*;
- Current (*A*)
- Power Factor (-1 to 1)
- Reactive Power- *kVar*.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
Use of natural gas	G_{CHP}	Nm^3/h	At the CHP	At each event
Electric energy produced during the event	P_{CHP}	kWhe	At the CHP	At each event
Thermal energy produced during the event	Q_{CHP}	kWht	At the CHP	At each event
Thermal energy used by the DH system during the event	Q_{DH}	kWht	At the district heating branch served by the CHP	At each event
Thermal losses during the event	Q_{Loss}	kWht	At the district heating branch served by the CHP	At each event
Electric energy used by the CHP out of the DH normal system	C_{CHP}	kWhe	At the CHP	Every minute

Table 13 –Technical monitoring parameters during the event (LO1)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
Real Power	$P_{real,s}$	kW	At the substation	Every minute
Max Real Power	$P_{real,s\ max}$	kW	At the substation	Every minute
Real Power Point Set-Point	$P_{real,s\ set}$	kW	At the substation	Every minute
Reactive Power	$P_{reac,\ s}$	kVAr	At the substation	Every minute
Reactive Power Set-Point	$P_{reac,\ s\ set}$	kVAr	At the substation	Every minute
Voltage	V_s	Volt	At the substation	Every minute
Power Factor	PF_s	Varying from -1 to 1	At the substation	Every minute
Max Positive Power Factor	$PF_{s\ max\ +}$	Varying from 0 to1	At the substation	Every minute
Max negative Power Factor	$PF_{s\ max\ -}$	Varying from -1 to 0	At the substation	Every minute
Current	I_s	A	At the substation	Every minute
Major fault indications	$Fault_{,s}$	I/O	At the substation	Every minute
DR availability	DR	kW	At the co-generator (CHP)	Every minute

Real Power	Pr_{CHP}	kW	At the co-generator (CHP)	Every minute
Voltage	V_{CHP}	Volt	At the co-generator (CHP)	Every minute
Current	I_{CHP}	A	At the co-generator (CHP)	Every minute
Power Factor	PF_{CHP}	Varying from -1 to 1	At the co-generator (CHP)	Every minute
Reactive Power	$P_{reac,CHP}$	kVar	At the co-generator (CHP)	Every minute

Table 14 -Non-Energetic monitoring parameters during the event (LO1)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
The fee guaranteed by the Distribution Network Operator (UKPN) to the co-generator manager (BEC) during the event	F_{CHP}	€/each event	At the co-generator	Every six months
The fines paid by UKPN	Fines	€	At the substation and surrounding network	Per network outage (missed event response/insufficient response)
The maintenance and operation extra-costs paid by BEC for the co-generator management	M_{CHP}	€/each event	At the cogenerator	Every six months

Table 15-Technical parameters for continuous monitoring (LO1)

3.1.7 London Demonstrator LO2-LO3

3.1.7.1 Demo Concept

London Borough of Islington Council has recently completed *the first phase* of Bunhill Heat and Power, a 1km heat network served by a $2MW_e$ gas CHP engine. *The second phase* will be developed in the framework of the Celsius project and corresponds to the realization, operation and monitoring of two demonstrators with the objective of developing a system to capture and utilize waste heat from identified local sources (LO2), in order to expand the actual Bunhill district heating system (LO3).
The two sources of waste heat, identified by Islington Council in charge of the Demonstrator's realization, are:

- UK Power Network's Substation: heat is generated from electrical transformers during their normal activity as a result of losses incurred during voltage conversion. At UK Power Network Ltd.'s (UKPN) City Road Substation, the transformers are cooled using an oil system and the heat is currently lost to the environment. The feasibility study indicated that the expected available heat of the three transformers is approximately 160 kW per transformer at full load, at oil temperatures assumed to be at least 48 °C;
- London Underground's mid-tunnel ventilation shaft: the ventilation shaft expels exhaust air at a rate of 30 m^3/s at a temperature of 22°C in winter and 28°C in summer. The heat output for the mid-tunnel ventilation shaft is estimated to be around 0.4MW.

Heat from these two sources will be captured using heat exchangers and heat pump systems, being able to provide heating to an additional 620 council owned homes and around 1.000 new build homes, 5.000 m^2 commercial space, student and hotel accommodation.
The plans include a hydraulic connection to the first phase's heat network, which currently serves 880 residential council homes and two leisure centres. Moreover, Islington Council plans to incorporate a thermal storage system near to the electrical substation heat pump to even out demand if necessary. CHP generation is also being considered to drive the heat pump.
A simplified layout of the process related to these Demonstrators is reported in the figure below.

celsius smart cities

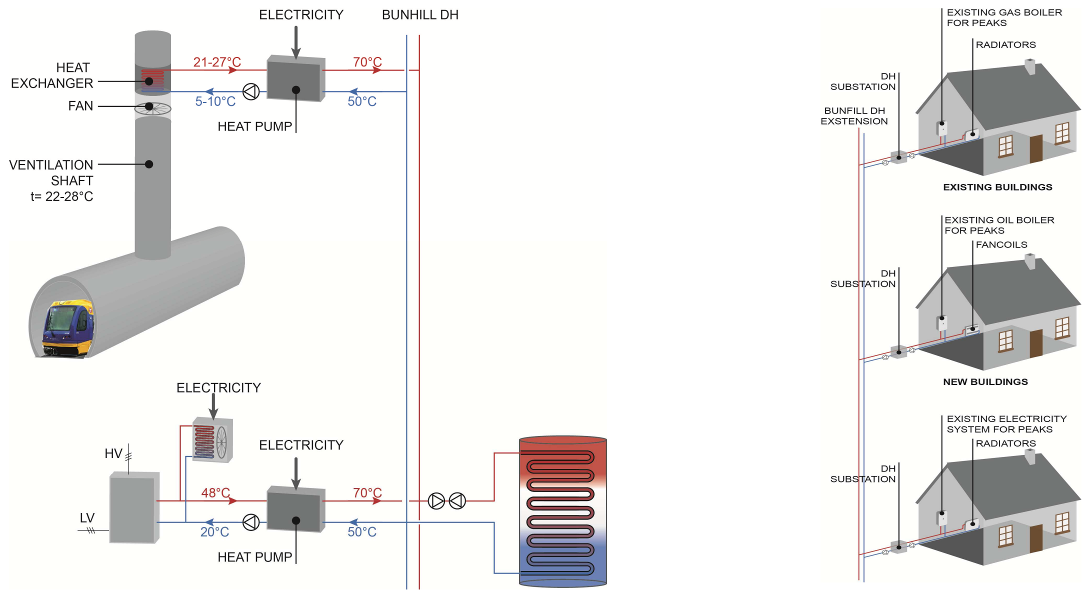

Figure 8- *Simplified layout- (LO2 -left side,- LO3-right side)*

3.1.7.2 List of parameters

A list of energetic monitoring parameters has been set-up in order to measure the performance of the waste heat sources utilization (LO2) and the impact of the extension of the DH system (LO3):

<u>VENTILATION SHAFT (A)</u>

- Electric energy consumption of the heat pump system- *kWhe*;
    - Used by the compressors;
    - Used for pumping systems;
    - Used for the external heat exchanger;

  Also peak consumption (kW) should be considered for each component.
- Electric energy consumption of the subway extraction system – *kWhe* ;
- Pressure drop across the heat exchanger in the ventilation shaft- *bar* ;

  Also peak consumption (kW) should be considered
- Temperatures at the subway extraction system - *°C*;

  Temperature should be measured both before and after the heat exchanger.
- Thermal energy (water flow rate, inlet and outlet temperature)- *kWht*;
    - At the heat pump;
    - At the external heat exchanger;

<u>TRANSFORMER (B)</u>

- Electric energy consumption of the heat pump system- *kWhe*;
    - Used by the compressors;
    - Used for pumping systems;
    - Used for the external heat exchanger;

  Also peak consumption (kW) should be considered for each component.
- Inlet and outlet oil temperature at the heat exchanger- *°C*;
- Inlet and outlet oil temperature in the normal cooling system - *°C*;
- Oil flow rate through the heat exchanger and through the conventional cooler- *kg/h*;

- Thermal energy- *kWht*;
    - At the heat pump;
    - At the transformer cooling system;

THERMAL STORAGE (C)

Actually London Borough of Islington is reasoning on different possibilities for thermal storage solutions. In any case a set of parameters to be monitored has been proposed in the list below; a revision/integration of the provided list may be required following the real implementation of the identified solution for the thermal storage

- Thermal energy, supply side- *kWh;*
- Thermal energy, users' side- *kWh*;
- Temperature profile in the storage system; *°C*

BUILDINGS connected to the DH in the expansion of the network (aggregated data)- (D)

- External temperature- *°C*;
- Thermal energy delivered to buildings connected to the DH in the project - *kWht* .

Apart from technical parameters to be monitored, a list of other significant non-energetic parameters has been identified:

- Tariff for thermal energy consumption paid by the end-user in buildings connected to the DH system- *€/kWht*;
- Maintenance cost for the ventilation shaft heat pump system- €;
- Maintenance cost for the transformer heat pump system- €;
- Maintenance cost for the thermal storage system- €;
- Tariff for the electric energy consumption paid by the network manager - $€/kWh_e$;
- Exhausted gas flow rate (Nm^3/h) and polluting emission concentrations (CO_2, CO, NO_x, SO_x, PM, PM_{10}, $PM_{2.5}$- mg/Nm^3) by the peak load boilers at buildings- Nm^3/h.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Electric energy consumption of the heat pump system at the ventilation shaft	$C_{hp, A}$	kWhe	Ventilation shaft	Hourly	-
Electric energy consumption of the subway extraction system	$C_{ex, A}$	kWhe	Ventilation shaft	Hourly	-
Inlet air temperature at the heat exchanger	$Te_{air,IN}$	°C	Ventilation shaft	Hourly	-
Outlet air temperature at the heat exchanger	$Te_{air,OUT}$	°C	Ventilation shaft	Hourly	-
Thermal energy at the heat pump system	$Q_{hp, A}$	kWht	Ventilation shaft	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy at the external heat exchanger	$Q_{he, A}$	kWht	Ventilation shaft	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Pressure drop across the heat exchanger	P_{drop}	bar	Ventilation shaft	Hourly	-
Electric energy consumption of the heat pump system at the transformer	$C_{hp, B}$	kWhe	Transformer	Hourly	-
Oil inlet temperature at the heat pump exchanger	$Te_{hp, IN}$	°C	Transformer	Hourly	-
Oil outlet temperature at the heat pump exchanger	$Te_{hp, OUT}$	°C	Transformer	Hourly	-
Oil inlet temperature at cooling system	$Te_{cool, IN}$	°C	Transformer	Hourly	-
Oil outlet temperature at cooling system	$Te_{cool, OUT}$	°C	Transformer	Hourly	-
Oil flow rate through the heat pump exchanger	$V_{oil,hp, B}$	lt/sec	Transformer	Hourly	-
Oil flow rate through the conventional cooler	$V_{oil,cool, B}$	lt/sec	Transformer	Hourly	-
Thermal energy at the heat pump system	$Q_{hp, B}$	kWht	Transformer	Hourly	-
Thermal energy at the transformer cooler	$Q_{cool, B}$	kWht	Transformer	Hourly	-

Thermal energy, supply side	$Q_{WS, C}$	Nm^3/h	Thermal storage	Hourly	-
Thermal energy, user's side	$Q_{WU, C}$	Nm^3/h	Thermal storage	Hourly	-
Temperature profile	$Ts,_k$	°C	Thermal storage (in different points *k*)	Hourly	-
Thermal energy delivered to buildings connected to the DH in the project	$Q_{build, i}$	kWht	At each building (i)	Hourly	Aggregated Data will be provided for elaboration
District heating production mix	$Q_{mix, DH}$	MWht and % composition	At the DH branch	Monthly	-
Fuel mix	$E_{, mix}$	MWh and % distribution of each source (nuclear, PV, wind, etc…)	At the electric grid connected to the CHP	Monthly	-

Table 16-Energetic monitoring parameters (LO2-3)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
Tariff for thermal energy consumption paid by the end-user in buildings connected to the DH system	$T_{th, end-user}$	€/kWht	At buildings connected to the district heating	Monthly
Maintenance cost for the ventilation shaft heat pump system	M_A	€	Ventilation shaft	Every six months
Maintenance cost for the transformer heat pump system	M_B	€	Transformer	Every six months
Maintenance cost for the thermal storage system	M_C	€	Thermal storage	Every six months
Tariff for the electric energy consumption paid by district heating network manager (DHM)	$T_{el, DHM}$	€/kWhe	Electric grid	Monthly
Exhausted gas flow rate (Nm^3/h) and polluting emission concentrations (CO_2, CO, NO_x, SO_x, PM, PM10- mg/Nm^3) by the peak load boilers at buildings	$G_{emission,i}$	Nm^3/h	At new buildings which will be connected to the district heating system if available, if possible according to periodical controls	Yearly average value

Table 17- Non-Energetic monitoring parameters (LO2-3)

3.1.8 Rotterdam Demonstrator RO1

3.1.8.1 Demo Concept

Rotterdam Heating Transport Company (Warmtebedrijf Rotterdam) implemented in the past a transport infrastructure with a thermal capacity of 105 MW to transport residual heat from the AVR-owned waste incinerator in the port area to residential areas in the southern and northern parts of the city of Rotterdam. The new infrastructure is an integrated double pipeline of 26 Kilometres.

RO1 Demonstrator ("The Heat Hub") is a physical structure placed at a strategic location near the waste heat transportation infrastructure and the district heating systems, whose aim is to act as a distribution station and connect the existing district heating systems in the south and north of Rotterdam. The heat hub is provided with:

- A well-insulated buffering tank (located in the middle of the distribution network in order to be closer to end-consumers);
- A smart ICT-system, representing a crucial element in the further optimization of heat sources, buffers, new connections and pumping stations in the waste heat transportation infrastructure of Warmtebedrijf Rotterdam.

This heat is transferred to the existing district heating network of Eneco by means of two plate heat exchangers.

The implementation of the RO1 demonstrator will allow Warmtebedrijf Rotterdam to store heat at the primary side of the heat hub by means of an atmospheric heat buffer. The heat buffer consists of a hot (approximately 98°C) and a relatively cold layer (approximately 60°C) and has a heat storage capacity of approximately 185 MW_t at a temperature difference between the cold and hot layer of 30°C. The main components of the heat hub are:

- A buffer loading and unloading pump;
- A return pump needed to transport the return water back to AVR (heat supplier);
- Two plate heat exchangers with a capacity of approximately 35 MW_t. These heat exchangers are the physical separation of the new built primary side and the existing secondary side (Eneco);
- Two secondary pumps needed to transport the return water of the secondary side through the plate heat exchangers to the hot supply line of the secondary side.

A simplified layout of the process related to this demonstrator is reported in the figure below.

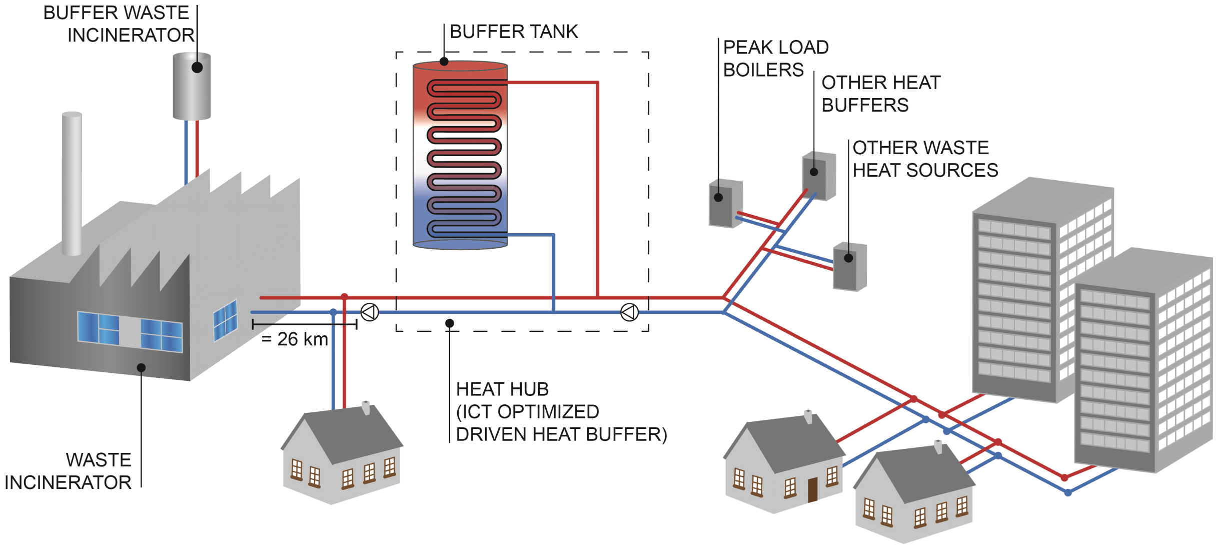

Figure 9- *Simplified layout (RO1)*

3.1.8.2 Parameters

The following list of monitoring parameters is a preliminary list and cannot be considered as the definitive one. Therefore, the provided list can be subject to possible modifications/updates in the next future according to feedback provided by plant managers.

The main monitoring parameters suggested for RO1 monitoring are listed below:

- Incoming thermal energy (from the waste incinerator to the Heat hub) – *kWht*;
  The data collected should be associated with the exact date and time in order to assess the amount of energy stored and reused and the losses.
- Outgoing thermal energy - *kWht*;
  The data collected should be associated with the exact date and time in order to assess the amount of energy stored and reused and the losses.
- Efficiency for loading and unloading buffer tank:
  - Electric energy consumption of the buffer pump - *kWhe:*
  - Thermal energy in and out of the buffer- MWh
- Maximizing capacity of heat exchanger by utilizing the buffer- *MWh*

A detailed table, specifying for each energetic and non-energetic parameter data type, data variable name, unit of measurements, location of measurement, recoding frequency and possible comments, is reported below:

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Incoming thermal energy	Q_{in}	kWht / GJ	At the use-side of the heat hub system	Hourly	The possibility to increase recording frequency up to 15 minutes will be evaluated with the demo responsible partners; indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Outcoming thermal energy	Q_{out}	kWht / GJ	At the supply-side of the heat hub system	Hourly	The possibility to increase recording frequency up to 15 minutes will be evaluated with the demo responsible partners; indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Electric energy consumption of buffer pump	C_{pump}	kWhe	At the supply-side of the heat hub system	Hourly	-
Thermal energy in and out of the buffer	Q_{buffer}	MWht	At the supply-side of the heat hub system	Hourly	-
Maximizing capacity of heat exchanger by utilizing the buffer	Capacity	MWht		Hourly	

Table 18-Energetic monitoring parameters (RO1)

3.1.9 Rotterdam Demonstrator RO2

3.1.9.1 Demo Concept

RO2 Demonstrator ("Industrial Ecology") overall objective is to integrate two industrial sites in Rotterdam district heating system. The industrial sites, a wastewater treatment plant (RWZI Dokhaven) and a grain processing plant (Meneba), are both located nearby the heat hub foreseen within RO1 demonstrator; thus, the connection between hub and plants will be implemented in order to allow heat exchanges between the plants by using the hub as a centre point.
RO2 Demonstrator will be implemented in two different phases:

- **Phase 1:** the water treatment facility "Dokhaven", produces approximately 3.570.700 m^3 of biogas per year, which is used in a CHP for the co-production of thermal and electric energy. Thermal energy is used for sustaining the waste water treatment processes which require a constant temperature of 31°C, but a large part of it is currently wasted. In the demonstrator the water treatment facility will deliver thermal energy from biogas fired cogenerator to Warmtebedrijf Rotterdam, allowing recovering 76.377 GJ of high temperature heat. In return, the wastewater treatment plant will be connected to the low-temperature return flow of the district heating network (cascade), utilizing 23.289 GJ of low-temperature heat for sustaining the wastewater treatment process;
- **Phase 2**: the second industrial site to integrate into the system is the grain processing plant "Meneba" that now is completely gas driven and which is located adjacent to the site of the old waste incinerator where the heat hub is built. At Meneba site, gas is currently burnt in conventional boilers to produce steam, which in turn is used in the industrial processes and for space heating, including the heat demand of activities with low temperature requirements. In order to optimize the energy efficiency in the industrial site, the demand for space heating will be supplied with heat generated from the biogas from the sewage plant (11.140 GJ) through the heat hub. The waste heat can also be used in parts of the production process.

<u>Data Centre</u>

Moreover, the KPN Waalhaven Rotterdam data centre located in south Rotterdam, a few kilometres from the Heat Hub-area, will be used as a theoretical demonstrator within the CELSIUS project. As a part of the CELSIUS project, the opportunities of integrating data centre with the waste heat transport infrastructure for cooling needs will be explored. In this case absorption cooling systems will be considered when the cooling capacity of the data centre is increased because of its expanding. The data centre is located 200 meters from the waste heat transport infrastructure in the south of Rotterdam and a few kilometres from the heat hub-area.

A simplified layout of the process related to this Demonstrator is reported in the figure below:

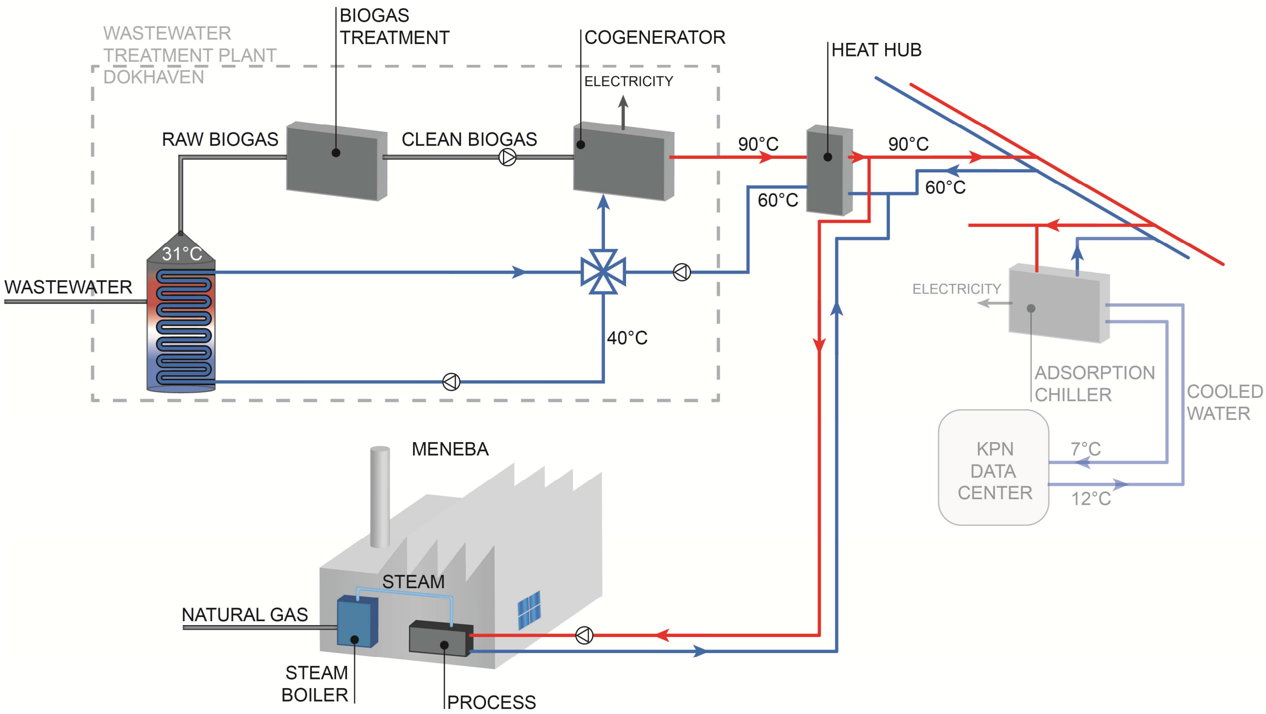

Figure 10 - *Simplified layout (RO2)*

3.1.9.2 Parameters

The following list of monitoring parameters is a preliminary list and cannot be considered as the definitive one. Therefore, the provided list can be subject to possible modifications/updates in the next future according to feedback provided by plant managers.

The main monitoring parameters suggested for RO2 monitoring are listed below:

Wastewater Treatment Plant (WWTP)

- Thermal energy supplied by the heat hub to the WWTP (calculated from water flow rate, inlet and outlet water temperature) - *kWht*;
- Thermal energy provided by the biogas fired co-generator to the heat hub (calculated from water flow rate, inlet and outlet water temperature)- *kWht* ;

Meneba

- Thermal energy provided by the heat hub to the Meneba grain processing plant (calculated from water flow rate, inlet and outlet temperature)- *kWht*;

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Thermal energy supplied by the heat hub to the WWTP	$Q_{WWTP,HH}$/ $Q_{WWTP, WWTP}$	kWht	At heat hub side or at Wastewater Treatment Plant side	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy provided by the biogas-cofired cogenerator to the heat hub	$Q_{CHP,HH}$/ $Q_{CHP,CHP}$	*kWht*	At heat hub side or at the cogenerator of the wastewater treatment plant	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)
Thermal energy provided by the heat hub to the Meneba grain processing plant	$Q_{Men,HH}$ / $Q_{Men,Men}$	kWht	At heat hub side or at the Meneba plant	Hourly	Indirect measures, coming from direct measurements of water flow (m^3/h), inlet water temperature (°C) and outlet water temperature (°C)

Table 19-Energetic monitoring parameters (RO2)

4. Specific monitoring protocols: existing demonstrators

As already mentioned in the introduction to the present document, the Celsius project includes 14 already existing and operational demonstrators which will be added to the analysis of the performance in order to cover a wider range of technologies, enlarging the Celsius City concept and providing useful results for the set up of the technical toolbox which will be developed in the future years of the project for enabling upscale and roll-out of all the demonstrators.
Moreover, monitoring of the existing demonstrators will be the basis for calculating specific KPIs which will be relevant in order to identify opportunities for optimizing the existing plants, reducing the pay-back periods and increasing return on investments.
The methodology followed for setting-up the monitoring parameters for the existing demonstrators has been substantially the same followed for the new demonstrators.
The existing demonstrators have been built in previous years answering to specific needs of the correspondent cities in which they have been conceived and applied. A Celsius-oriented approach has been followed for setting-up a list of specific KPIs by focusing the efforts on the identification of a sub-set of parameters useful for the calculation of relevant KPIs which are really meaningful for the purposes of the Celsius project in terms of potential of replicability of the implemented technical solutions in other similar contexts.
Moreover, in most cases recording frequency scheduled for each monitored parameter is reduced in comparison to the new demonstrators, considering that the existing demonstrators are steady-state systems operating since several years.

4.1.1 Gothenburg demonstrator 9GOe

4.1.1.1 Demo Concept

This demonstrator consists of a combined heat and power plant which aims at producing thermal and electric energy from renewable sources, i.e. wood chips. The plant was originally built in 1985 as a coal boiler used for heating purposes; later, in 2004 the previous coal boiler was converted into a renewable biomass plant for thermal energy production and then, in 2010 a CHP system was implemented in order to produce also electric energy.

4.1.1.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Thermal energy produced and delivered to the district heating - *MWht*;
- Electric energy produced and delivered to the grid - *MWhe*;
- Electric energy consumed internally - *MWhe*;
- Fuel (wood chips) consumed - *kg or MWh*;
- Energy content in fuel (wood chips) - *MWh /kg*;
- District heating supply temperature -*°C*;
- District heating return temperature - *°C*;
- Thermal energy produced in coal boiler and delivered to the district heating before reconstruction - *MWht*;
- Coal consumed before reconstruction - *kg or MWh*;
- Energy content in fuel (coal) - *MWh/kg*;
- District heating production mix - *MWh and % composition.*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Thermal energy produced and delivered to district heating	Q_{CHP}	MWht	Output from CHP plant to DH network	Monthly	-
Electric energy produced and delivered to the grid	P_{CHP}	MWhe	Output from CHP plant to grid	Monthly	-
Electric energy consumed internally	C_{CHP}	MWhe	CHP plant	Monthly	-
Fuel (wood chips) consumed	$V_{biomass}$	kg or MWh	Delivered to CHP plant	Monthly	-
Energy content in fuel (wood chips)	$H_{biomass}$	MWh/kg	Wood chips	Average	If amount of consumed fuel is given in kg.
District heating supply temperature	$Te_{s, DH}$	°C	Output from CHP to DH network	Monthly	-
District heating return temperature	$Te_{r, DH}$	°C	Input to CHP from DH network	Monthly	-
Heat produced in coal boiler and delivered to district heating before the reconstructions	$Q_{baseline}$	MWht	Output from old heat plant to DH network	Monthly data during one year e.g. 1990	-
Coal consumed before reconstruction	$C_{baseline}$	kg or MWh	Delivered to old heat plant	Monthly (if available, otherwise yearly average data will be taken into account)	-
Energy content in fuel (coal)	$H_{baseline}$	MWh/kg	Coal	Average	If amount of consumed fuel is given in kg.
District heating production mix	$Q_{mix,DH}$	MWh and % composition	At production facilities	Yearly	District heating production mix

Table 20 - Technical monitoring parameters (9GOe)

Apart from the technical parameters, aimed at evaluating the energy efficiency of the demonstrator, the following economic parameters will be also collected:

- Investment cost for the conversion of old coal plant into biofuel plant in 2004- €;
- Depreciation time for reconstruction/conversion equipment in 2004- *years*;
- Investment cost of combined heat and power equipment installed in 2010-€;
- Depreciation time for CHP equipment in 2010- *years*;
- Wood chips price – *€/kg or €/MWh (monthly data)*;
- Coal price, during the same year considered for the wood chips price (e.g., 2013)- *€/kg or €/MWh*;
- Selling price of produced electric energy- *€/kWhe*;
- Selling price of produced heat- *€/kWht*;
- Operation costs-*€/year*;
- Maintenance costs-€.

A summary table with the list of the identified economic parameters is reported in the table below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Investment cost for the conversion of old coal plant into biofuel plant in 2004	$I_{biofuel}$	€	-
Depreciation time for reconstruction/conversion equipment in 2004	$t_{d, biofuel}$	Years	-
Investment cost of combined heat and power equipment installed in 2010	I_{CHP}	€	-
Depreciation time for CHP equipment in 2010	$t_{d, CHP}$	Years	-
Wood chips price	$T_{wood, DHM}$	€/kg or €/MWh	Monthly
Coal price, during the same year considered for the wood chips price (e.g., 2013)-	$T_{coal, DHM}$	€/kg or €/MWh	Monthly
Selling price of produced electric energy	$S_{el, DHM}$	€/MWhe	Monthly
Selling price of produced heat	$S_{th, DHM}$	€/MWht	Monthly
Operation costs	O_c	€	Yearly
Maintenance costs	M	€	Yearly

Table 21 – ***Non***-Energetic monitoring parameters (9GOe)

4.1.2 Gothenburg demonstrator 29GOe

4.1.2.1 Demo Concept

The overall aim of this demonstrator is to offer the customers a non-conventional energy contract ("Climate Agreement") by providing a set indoor temperature (e.g. 21 °C) at a fixed cost, instead of a certain quantity of energy (kWh). The proposed agreement is offered either for a five or three years duration and by now has been undersigned by customers within different areas for a total extension of 3.6 million square meters. The energy company (GOTE) takes responsibility of the building energy system and by the agreement gets incentives to save energy as well as continuously maintain the system, providing also information to customers about their energy consumptions.

4.1.2.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Total thermal energy delivered by the district heating to buildings having adopted the "Climate Agreement" contract- *MWht*;
- Thermal energy delivered to representative buildings with agreements - *MWht*;
- District heating delivered to buildings before having signed the agreements- *MWht*;
- Indoor temperatures in representative buildings- *°C*
- District heating production mix- *MWh and % of each fuel respectively*;

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Total thermal energy delivered by the district heating to buildings with agreements	Q_{agreem}	MWht	At buildings with climate agreements, total	Yearly	-
Thermal energy delivered to representative buildings with agreements	$Q_{agreem, ref-i}$	MWht	At buildings with climate agreements, five representative buildings(*i*) with climate agreements	Yearly	-
District heating delivered to buildings before having signed the agreements	$Q_{baseline, ref-i}$	MWht	At five representative buildings (*i*) with climate agreements	Yearly	-
Indoor temperatures	$Te_{indoor, ref-i}$	°C	At five representative buildings (*i*) with climate agreements	Hourly	-
District heating production mix	$Q_{mix,DH}$	MWh and % composition	At production facilities	Yearly	-

Table 22 - Technical monitoring parameters (29GOe)

Apart from the technical parameters, aimed at evaluating the energy efficiency of the demonstrator, a set of non energetic parameters to be monitored and recorded has been identified and listed below:

- Number of customers;
- Total floor area of buildings benefitting of the “climate agreement”- m^2;
- Floor area of five representative buildings benefitting of the “climate agreement”- m^2;
- Investment cost of the equipment necessary for temperature control in five representative buildings- €;
- Operation and maintenance costs in five representative buildings - €;
- Depreciation time for the equipment installed in five representative buildings- *year*;
- Yearly savings for energy company with reference to five representative buildings - *€/year*;
- Tariff for thermal energy with “climate agreement” in five representative buildings - *€/kWht*;
- Tariff for thermal energy (delivered to customer) in five representative buildings before having signed the “climate agreement”- *€/kWht*;

A summary table with the list of the identified economic parameters is reported in the table below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Number of customers	N_c	*Number*	Yearly
Total floor area of buildings benefitting of the "climate agreement"	A_{temp}	m^2	Yearly
Floor area of five representative buildings benefitting of the "climate agreement"	$A_{temp,ref}$	m^2	-
Investment cost of equipment necessary for control in five representative buildings	I	€	-
Operation and maintenance costs in five representative buildings	M	€	Yearly
Depreciation time for the equipment installed in five representative buildings	$t_{d,ref}$	*years*	-
Yearly savings for energy company in five representative buildings	Sv_{ref}	€	Yearly
Tariff for thermal energy with" climate agreement" in five representative buildings	$T_{th, end-user}$	*€/kWht*	Yearly
Tariff for thermal energy (delivered to customer) in five representative buildings before having signed the "climate agreement"	$T_{th, end-user, baseline}$	*€/kWht*	Yearly

Table 23 – Non Energetic monitoring parameters (29GOe)

4.1.3 Gothenburg demonstrator 19GOe

4.1.3.1 Demo Concept

The aim of this demonstrator, “Absorption cooling”, is to produce cooling for the district cooling network by means of absorption chillers. The thermodynamic cycle of the absorption chillers is driven by a heat source and, considering this demonstrator, thermal energy from district heating is used as heat source. Total installed capacity is 30 MW and 45 GWh cooling are produced annually, corresponding to 37 % of the total district cooling (DC) production in Gothenburg.

4.1.3.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Cooling energy delivered from absorption chillers to district cooling network- *MWht*;
- District cooling network supply temperature -*°C*;
- District cooling network return temperature-*°C*;
- District heating supply temperature-*°C*;
- District heating return temperature-*°C*;
- Chillers’ electric energy consumption - *MWhe*;
- Total cooling energy produced at production facilities- *MWht*;
- Total cooling energy delivered at customers substations- *MWht*;
- Electric energy consumption of the district cooling distribution network - *MWhe*;
- Amount of refrigerants/chemicals used- *kg*;
- District heating production mix- *MWh*;
- Heat loss in the district heating network - *MWht*;
- Electric energy consumption of the district heating distribution network- *MWhe*;

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Cooling energy delivered by absorption chillers to district cooling network	$Q_{c, DC}$	MWht	Production facility	Monthly	
District cooling network supply temperature	$Te_{s, DC}$	°C	Production facility, outlet to district cooling network	Monthly	
District cooling network return temperature	$Te_{r, DC}$	°C	Production facility, inlet to chillers from district cooling network side	Monthly	
District heating supply temperature	$Te_{s, DH}$	°C	Production facility, inlet to chillers from district heating	Monthly	
District heating return temperature	$Te_{r, DH}$	°C	Production facility, outlet from chillers back to district heating	Monthly	
Chillers' electric energy consumption	C_c	MWhe	Production facility, including pumps and other equipment	Monthly	
Total cooling energy produced at production facilities	Q_{DC}	MWht	All DC production facilities	Yearly	
Total cooling energy delivered at customers substation	Q'_{DC}	MWht	District cooling customer substations	Yearly	
Electric energy consumption of the district cooling distribution network	C_{DC}	MWhe	District cooling distribution network	Yearly	
Amount of refrigerants/chemicals used	R	kg	Absorption chillers	Yearly	
District heating production mix	$Q_{mix, DH}$	MWht and % composition	District heating production facilities	Monthly	
Heat loss in the district heating network	$Q_{loss,DH}$	%	District heating network	Yearly	(ratio between the delivered heat to customer substations and the produced heat)
Electric energy consumption of the district heating distribution network	C_{DH}	MWhe	District heating network	Yearly	

Table 24 - Energetic monitoring parameters (19GOe)

Apart from the technical parameters, aimed at evaluating the energy efficiency of the demonstrator, a set of non energetic parameters to be monitored and recorded has been identified and listed below:

- Number of customers connected to district cooling;
- Total cooled area of buildings connected to district cooling network- m^2;
- Type of buildings connected to district cooling network (residential/commercial) - *% per category*;
- Investment cost for absorption chillers - €;
- Depreciation time – *years*;
- Tariff paid by the district cooling network manager (DCM) for electric energy used for absorption chillers - *€/MWhe*;
- Tariff paid by the district cooling network manager (DCM) for thermal energy consumption from district heating used in absorption chillers - *€/MWht*;
- Operation and maintenance cost- €;
- Investment cost of district cooling network- €;
- Depreciation time of district cooling network – *years*;
- Operation and maintenance costs of district cooling network -€;
- Selling price of produced cold (to customer, average) -*€/kWh.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Number of customers connected to the cooling system	N	Number	Yearly
Total floor area of buildings connected to the district cooling network	A_{DC}	m^2	Yearly
Type of buildings connected to the district cooling network (residential/commercial)	-	% per category	Yearly
Investment cost for absorption chillers	I_c	€	-
Depreciation time	$t_{p,c}$	Years	-
Tariff paid by the district cooling network manager (DCM)for electric energy used for absorption chillers	$T_{el, DCM}$	€/MWhe	Monthly
Tariff paid by the district cooling network manager (DCM) for thermal energy consumption from district heating used in absorption chillers	$T_{th, DCM}$	€/MWht	Monthly
Operation and maintenance costs	M	€	Yearly
Investment cost of district cooling network	I_{DC}	€	-
Depreciation time of district cooling network	$t_{p,DC}$	Years	-
Operation and maintenance cost of district cooling network	M	€	Yearly
Selling price of produced cold (to customer, average)	$T_{DC, end user}$	€/MWht	Monthly

Table 25 – Non Energetic monitoring parameters (19GOe)

4.1.4 Gothenburg demonstrator 11GOe

4.1.4.1 Demo Concept

The aim of this demonstrator, “Cooling by river water”, is to produce cooling for the district cooling network by means of using river water in heat exchangers as cold source. Total installed capacity is 15 MW and 43 GWh are yearly produced, corresponding to 35 % of the total district cooling production in Gothenburg.

4.1.4.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Cooling energy delivered from river water to district cooling network- *MWht*;
- District cooling network supply temperature -*°C*;
- District cooling network return temperature-*°C*;
- Inlet temperature of river water in the heat exchangers-*°C*;
- Outlet temperature of river water from the heat exchangers (back to the river)-*°C*;
- Electric energy consumption for pumping systems for the heat exchangers - *MWhe*;
- Total cooling energy produced at production facilities- *MWht*;
- Total cooling energy delivered at customers substations- *MWht*;
- Electric energy consumption of the district cooling distribution network - *MWhe.*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Cooling energy delivered from river water to district cooling network	$Q_{r,DC}$	MWht	Production facility	Monthly	
District cooling network supply temperature	$Te_{s, DC}$	°C	Production facility, outlet from heat exchanger, on district cooling network side	Monthly	
District cooling network return temperature	$Te_{r, DC}$	°C	Production facility, inlet to heat exchanger, on district cooling network side	Monthly	
Inlet temperature of river water in the heat exchangers	$Te_{s,river}$	°C	Production facility, inlet to heat exchanger, on river side	Monthly	
Outlet temperature of river water from the heat exchangers	$Te_{r,river}$	°C	Production facility, outlet from heat exchanger, on river side	Monthly	
Electric energy consumption for pumping systems for the heat exchangers	$C_{r,DC}$	MWhe	Production facility, including pumps and other equipment	Monthly	
Total cooling energy produced at production facilities	Q_{DC}	MWht	All district cooling production facilities	Yearly	
Total cooling energy delivered at customers substations	Q'_{DC}	MWht	District cooling customer substations	Yearly	
Electric energy consumption of the district cooling distribution network	C_{DC}	MWhe	District cooling distribution network	Yearly	

Table 26 - Energetic monitoring parameters (11GOe)

Apart from the technical parameters, aimed at evaluating the energy efficiency of the demonstrator, a list of non energetic parameters to be monitored and recorded has been identified and listed below:

- Number of customers connected to district cooling;
- Total cooled area of buildings connected to the district cooling network- *m²*;
- Type of buildings connected to the district cooling network (residential/commercial) - *% per category*;
- Investment cost for the river water district cooling facilities - €;
- Depreciation time – *years*;
- Tariff paid for the electric energy consumptions by the district cooling network manager (DCM)- *€/MWhe*;
- Operation and maintenance cost of river water district cooling facilities - €;
- Investment cost of district cooling network- €;
- Depreciation time of district cooling network – *years*;
- Operation and maintenance cost of district cooling network -€;
- Selling price of produced cold (to customer, average) -€.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Number of customers connected to district cooling	N	Number	Yearly
Total cooled area of buildings connected to district cooling	A_{DC}	m^2	Yearly
Type of buildings connected to district cooling (residential/commercial)	-	% per category	Yearly
Investment cost for river water district cooling facilities	I_f	€	-
Depreciation time	$t_{p,c}$	years	-
Tariff paid for the electric energy consumptions by the district cooling network manager (DCM)	$T_{el, DCM}$	€/MWhe	Monthly
Operation and maintenance cost of river water district cooling facilities	M_f	€	Yearly
Investment cost of district cooling network	I_{DC}	€	-
Depreciation time of district cooling network	$t_{p,DC}$	years	-
Operation and maintenance cost of district cooling network	M_{DC}	€	Yearly
Selling price of produced cold (to customer, average)	$T_{th, end\ user}$	€/MWht	Monthly

Table 27 – Non Energetic monitoring parameters (11GOe)

4.1.5 Gothenburg demonstrator 20GOe

4.1.5.1 Demo Concept

The 20GOe demonstrator is a system of solar collectors placed on the roof of a multi-dwelling building in Gårdsten, Göteborg. The building is connected to the district heating network and the installed system offsets the district heating demand of the building by supplying heat from a renewable source to heat internal spaces and to produce domestic hot water, by reducing the quantity of heat that has to be produced at Göteborg Energi’s production facilities.

4.1.5.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Supply temperature of hot water produced by the solar collectors system- *°C*;
- Heat produced by the solar collectors system- *MWht*;
- District heating supply temperature- *°C*;
- District heating return temperature- *°C*;
- Collector area- m^2;
- Direction;
- Tilt angle: °;
- Electric energy consumption- *MWhe.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Supply temperature of hot water	$Ts,_{SC}$	°C	Solar collectors	Hourly	
Heat production	Q_{SC}	MWht	Solar collectors	Hourly	
DH supply temperature	$T_{S,DH}$	°C	District heating connection at one production facility	Hourly	
DH return temperature	$T_{R,DH}$	°C	District heating connection at one production facility	Hourly	
Collector area	A_{coll}	m^2	Solar collectors	-	
Direction	Dir	(point of compass)	Solar collectors	-	
Tilt angle	Deg	°	Solar collectors	-	
Electric energy consumption	C	MWhe	Solar collectors	Monthly	

Table 28 - Energetic monitoring parameters (20GOe)

Other non-energetic parameters which will be useful to monitor and record are listed below:

- Investment costs (possibly updated by taking into account the current market conditions for the implemented technology)- €
- Maintenance costs- €
- Operating costs- *€/year*
- Tariff for heat consumption paid by the end-users- *€/kWht*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Investment costs	I	€	-
Maintenance costs	M	€	Yearly
Operating costs	Oc	€	Yearly
Tariff for heat consumption paid by the end-users	$T_{th,end\text{-}user}$	€/kWht	Monthly

Table 29 - Non-Energetic monitoring parameters (20GOe)

4.1.6 Gothenburg demonstrator 8GOe

4.1.6.1 Demo Concept

The 8GOe demonstrator aims at recovering the waste heat from an incineration plant in Gothenburg, operated by Renova (a waste management and recycling company). The demonstrator consists of a combined heat and power plant that produces both electric and thermal energy. The walls in the combustion chamber of the incinerator are covered with tubes containing water which is evaporated into saturated steam before being expanded in a turbine that is connected to a generator producing electric energy. After the turbine, the hot steam is cooled with district heating water and the transferred heat is delivered to the network. Also flue gas from the combustion chamber is cooled down by providing additional heat to the district heating network.

4.1.6.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Thermal energy produced at the waste incinerator plant- *MWht*;
- Thermal energy produced by the district heating system- *MWht*;
- Electric energy production- *MWhe*;
- Internal consumption of electric energy- *MWhe*;
- Amount of waste incinerated- *tons*;
- Energy content of waste *MWh/kg.*

Other relevant non-energetic parameters which will be monitored for this demonstrator are:

- Investment cost (possibly actualized by taking into account the current market conditions for the implemented technology)- €;
- Maintenance costs- €;
- Operating costs (including costs/revenue for waste)- *€/year*;
- Tariff for thermal energy consumption paid by the end-users- *€/kWht.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Heat produced at the waste incinerator plant	Q_{inc}	MWht	At the incineration plant	Hourly	
Total heat produced by the DH system	$Q_{mix, DH}$	MWht	All district heating production facilities	Yearly	
Electric energy production	P_{inc}	MWhe	At the incineration plant	Monthly	
Internal consumption of electric energy	C_{inc}	MWhe	At the incineration plant	Monthly	
Amount of waste incinerated	V_{waste}	tons	At the incineration plant	Monthly	
Energy content of waste	H_{waste}	MWh/kg	At the incineration plant	Yearly	If available, real data from operation will be used; otherwise a literature analysis will be carried out

Table 30 - Energetic monitoring parameters (8GOe)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Investment costs	I	€	
Maintenance costs	M	€	Yearly
Operating costs (including costs/revenue for waste)	Oc	€/year	Yearly
Tariff for thermal energy consumption paid by the end-users	$T_{th,end-user}$	€/kWht	Monthly

Table 31 –Non-energetic monitoring parameters (8GOe)

4.1.7 *Gothenburg demonstrator 7GOe*

4.1.7.1 Demo Concept

The demonstrator includes two waste heat recovery facilities that are part of the Gothenburg district heating system. Waste heat from two oil refineries (Preem and Shell) are recovered and delivered to the district heating grid. Thanks to the implementation of this demonstrator, thermal energy that would otherwise be lost to the environment is used to heat homes and produce domestic hot water. As a result, primary energy consumption at Göteborg Energi's own facilities can be consequently reduced.

4.1.7.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Amount of waste heat recovered (at each recovery site) - *MWht*;
- Waste heat temperature- *°C*;
- Total heat produced by the district heating system - *MWht*;
- District heating supply temperature-*°C*;
- District heating return temperature-*°C*;
- Electric energy consumptions of the heat pumps (at each recovery site) - *MWhe*;
- Pipe length (at each recovery site) – *m*.

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below.

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Amount of waste heat recovered at each site	$Q_{rec,DH}$	MWht	Each waste heat recovery site	Hourly	
Waste heat temperature	T_{waste}	°C	Each waste heat recovery site	Hourly	
Total heat production of district heating system	$Q_{mix,DH}$	MWht	All district heating production facilities	Yearly	
District heating supply temperature	$Te_{s,DH}$	°C	District heating connection at one production facility	Hourly	
District heating return temperature	$Te_{r,DH}$	°C	DH connection at one production facility	Hourly	
Electric energy consumptions of the heat pumps	C_{hp}	MWhe	Each waste recovery site	Monthly	
Pipe length	L_{pipe}	m	Each waste recovery site	-	

Table 32 - Energetic monitoring parameters (7GOe)

Apart from the energetic parameters, aimed at evaluating the energy efficiency of the demonstrator, a list of non-energetic parameters to be monitored and recorded has been identified and listed below:

- Investment cost (updated costs) - €;
- Maintenance costs- €;
- Operating costs- €;
- Fee paid by the district heating manager (DHM) for waste heat recovery- *€/MWht*;
- Tariff for thermal energy consumption paid by the end-users - *€/kWht.*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Investment cost (updated costs)	I_{today}	€	-
Maintenance costs	M	€	Yearly
Operating costs	O_c	€	Yearly
Fee paid by the district heating manager (DHM) for waste heat recovery	$F_{th, DHM}$	€/MWht	Monthly
Tariff for thermal energy consumption paid by the end-users	$T_{th, end-user}$	€/kWht	Monthly

Table 33 – Non energetic monitoring parameters (7GOe)

4.1.8 Gothenburg demonstrator 36GOe

4.1.8.1 Demo Concept

The demonstrator encompasses the entire district heating system and is intended to give an overview of an existing, mature district heating system in operation. District heating has been developed in Gothenburg since 1953. The system has gradually expanded in terms of geographical size of the network, number of customers connected and number of production facilities. Over the course of the decades, the sources of heat have changed radically, through the conversion of existing production plants to other fuels as well as through the addition of new heat production plants and technologies.

4.1.8.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Thermal energy delivered to customers per sector (i.e., sectors: single-family homes, multi-dwelling buildings, commercial/public buildings, industries, ground heat). – *MWht/sector*;
- Thermal energy production at each production facility- *MWht*;
- Electric energy production at each CHP facility; *MWhte*;
- Outdoor temperature -*°C*;
- Primary energy input at each production facility – *MWh*;
- District heating supply temperature -*°C*;
- District heating return temperature -*°C*;
- Electric energy consumption (at each recovery site) - *MWhe*;
- Pipe length - km;

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY	NOTES
Thermal energy production at each facility	$Q_{f, DH}$	MWht	DH connection at each production facility (f)	Hourly	-
Thermal energy delivered to customers, per sector	$Q_{sector, DH}$	MWht	Sum of measurements at each point of delivery (customer)	Hourly	Option: annual figures per sector, hourly total consumption Sectors: single-family homes, multi-dwelling buildings, commercial/public buildings, industries, ground heat.
Electric energy production at each CHP facility	$Q_{CHP, i}$	MWhe	At each CHP facility (*i*)	Monthly	
Outdoor temperature	Te_{ext}	°C	At city level	Hourly	-
Primary energy input at each production facility	$Q_{primary, DH}$	MWh (or other relevant unit depending on type of energy)	Production facilities	Monthly	-
District heating supply temperature	$Te_{s,DH}$	°C	DH connection at one production facility	Hourly	-
District heating return temperature	$Te_{r,DH}$	°C	DH connection at one production facility	Hourly	-
Electric energy consumption	$C_{f, DH}$	*MWhe*	at each recovery site	Hourly	
Pipe length	L_{pipe}	km	-	-	-

Table 34 - Technical monitoring parameters (36GOe)

Apart from the technical parameters, aimed at evaluating the energy efficiency of the demonstrator, a list of non-energetic parameters to be monitored and recorded has been identified and listed below:

- Tariff for heat consumption paid by the end-users - *€/kWht.*
- Maintenance costs- €;
- Operating costs- €;
- Revenues from sold thermal energy for the district heating network manager- €;
- Yearly investment - €;
- Number of users/customers in different sectors;

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Tariff for heat consumption paid by the end-users	$T_{th,\ end\text{-}user}$	€/kWht	Monthly
Maintenance costs	M	€	Yearly
Operating costs	O_c	€	Yearly
Revenues from sold thermal energy for the district heating network manager	R_{th}	€	Yearly
Yearly investment	I_{yearly}	€	Yearly
Number of users/customers in different sectors	N_c	-	-

Table 35 – Non energetic monitoring parameters (36GOe)

4.1.9 Cologne demonstrator 12 COe

4.1.9.1 Demo Concept

The residential area Köln-Stammheim is located in the north of Cologne. The local housing association GAG Immobilien AG owns 1.700 apartments and 100 houses there. From 2005 to 2007 GAG modernized 633 apartments and 87 houses. The yearly thermal energy required for heating these buildings is about 10 GWh. One of the largest sewage treatment plants in Germany (Großklärwerk Stammheim) is located one kilometre away from the residential area.
In 2010 the municipal water company (Stadtentwässerungsbetriebe StEB), GAG Immobilien AG and RheinEnergie AG started a joint project to exploit biogas produced by the digester for supplying heat to the residential area in Stammheim. For this purpose, StEB invested about 11.5 million € in an existing CHP to improve the electrical efficiency and the use of the heat. RheinEnergie AG built a peak and backup boiler to compensate the seasonal variations due to the fluctuation of biogas production and a one kilometer connecting pipe from the sewage plant to the residential area. For allocation to the houses, RheinEnergie bought and refurbished the existing five-kilometres pipeline network in Stammheim by globally investing invested 4.7 million €. On average, the required heat is supplied at 80 % by the biogas fired CHP. The rest is generated by natural gas. The new, innovative concept has lead to an estimating saving of 4,100 tonnes of CO_2 per year and a cost reduction for the residents by 17 %.

4.1.9.2 Parameters

The most important technical parameters to be monitored and recorded are:

- Thermal energy produced and delivered to district heating- *MWht*
- Electric energy produced and delivered to grid- *MWhe*
- Electric energy consumed internally- *MWhe*
- Fuel (digester gas and natural gas) consumed- *MWh*

A detailed table, specifying for each technical parameter data type, data variable name, unit of measurements, location of measurement, recording frequency and possible comments, is reported below:

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
Thermal energy produced and delivered to district heating	Q_{CHP}	MWht	Output from CHP plant to DH network	quarterly
Electric energy produced and delivered to grid	P_{CHP}	MWhe	Output from CHP plant to electricity grid	quarterly
Electric energy consumed internally	C_{CHP}	MWhe	In CHP plant	quarterly
Fuel (digester gas and natural gas) consumed	V_{gas}	MWh	Delivered to CHP plant	quarterly

Table 36 - Technical monitoring parameters (12COe)

Other relevant non-energetic parameters to be monitored/recorded are listed below:

- Operating costs- €
- Depreciation costs- €

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Operating costs	Oc	€	quarterly
Depreciation costs	Dc	€	quarterly

Table 37 - Non-energetic parameters for monitoring (12COe)

4.1.10 Cologne demonstrator 6COe

Besides the District Heating, RheinEnergie AG is promoting heat supply solutions in local areas in the city. In the 80 and 90s the heat production was gas based only. In the last years RheinEnergie extended the sources for the heat production trying to use environmentally sustainable sources. Up to 2013 several technical facilities of this type were brought into service:

- 9 bio-methane projects (6,000 kW heat, 80 GWh bio-methane),
- 10 geothermal heating (heating power between 8-70 kW)
- 4 wood pellet projects (100 – 850 kW; 600 t p.a.)
- 6 thermo solar heating systems (10 – 120 kW; collector surface 13 – 155 m^2)

Thermo solar systems are used for water heating at our local heat supply sites. They have a smallish part of the whole energy consumption at the sites. In reference to the main issue of CELSIUS – large scale systems for urban heating and cooling – it is relevant to report about a geothermal heating project in Herler Carre, in the Cologne district Buchheim, where several houses are built on a 20,000 m^2 plot. Three heat pumps are installed to use geothermal energy for heating. The residential complex will consist in its final state of about 250 apartments with underground parking spaces.

4.1.10.1 Parameters

The most important technical parameters suggested for being monitored and recorded are:

- Thermal energy produced by each heat pump-*MWht*
- Gas consumption of each heat pump- *MWh*
- Electric energy consumption of each heat pump- *MWhe*

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	LOCATION OF MEASUREMENTS	RECORDING FREQUENCY
Thermal energy produced by each heat pump	$Q_{hp,i}$	MWht	At each heat pump (i)	quarterly
Gas consumption of each heat pump	$V_{gas,i}$	MWh	At each heat pump (i)	quarterly
Electric energy consumption of each heat pump	$C_{hp,i}$	MWhe	At each heat pump (i)	quarterly

Table 38 - Technical parameters for monitoring (6COe)

DATA TYPE	DATA VARIABLE	UNITS OF MEASUREMENT	RECORDING FREQUENCY
Operating costs	Oc	€	quarterly
Depreciation costs	Dc	€	quarterly

Table 39 - Non-energetic parameters for monitoring (6COe)

5. Conclusions

The Celsius project aims at developing, optimizing and promoting smart decentralized heating and cooling systems in cities by consistently contributing to the reduction of CO_2 emission and of primary energy consumption.
The project involves five different cities (Gothenburg, Cologne, Genoa, London and Rotterdam) and foresees the realization and monitoring of 10 new demonstrators covering different aspects of energy efficient technologies, systems and practices.
Besides the new demonstrators that will be realized and operated during the Celsius project, existing energy efficient demonstrators are also included in the project, aimed at covering a wide range of state-of-the-art energy efficient solutions.
In the present work a common monitoring methodology applicable to different demonstrators has been set-up in order to follow a common approach for the evaluation of demo performances in view of potential future replicability of the projects in similar contexts. In particular the defined monitoring strategy includes two different aspects:

- Monitoring of the progress in the **design and realization of the new demonstrators**
- Monitoring the **performance of new and existing demonstrators**

For both the aspects, a common template for data collection has been elaborated and shared with demo responsible partners, by identifying the categories of essential information to be collected and by defining a common nomenclature in order to harmonize the subsequent elaboration phases at project level.
Then, the elaborated methodology has been applied to each specific case (both existing and new demonstrators) by defining a specific monitoring plan of each single demonstrator included in the project, identifying energetic and non-energetic parameters which are relevant for the future monitoring in order to calculate the general and specific KPIs providing a quantitative estimation of the main achievements related to the implementation of the Celsius project.

Appendix

List of acronyms

B: Boiler
BS: Building Substation
CHP: Combined Heat and Power cogenerator
DH: District Heating
DHM: District Heating Manager
DR: Demand Response
HH: Heat Hub
IC: Incineration Company
LV: Lamination Valves
R: Room
TE: Turbo Expander

List of symbols

GE1- Energetic parameters
$G_{B,i}$: Natural gas flow at each boiler, [Nm^3/h]
G_{CHP}: Natural gas flow at the cogenerator, [Nm^3/h]
G_{TE}: Natural gas flow at the turbo-expander, [Nm^3/h]
G_{LV}: Natural gas flow at the lamination valves, [Nm^3/h]
$Q_{B,i}$: Heat flow at each boiler, [kWht]
Q_{CHP}: Heat flow at the cogenerator, [kWht]
Q_{TE}: Heat flow at the turbo expander, [kWht]
Q_{LV}: Heat flow at the lamination valves, [kWht]
$Q_{DH,j:}$ Heat flow at the district heating, [kWht]
$Q_{BS,\ k}$: Heat flow at the building substation, [kWht]
$Q_{R,\ h}$: Heat flow at each room, [kWht]
Te_{CHP}: Stack temperature at CHP, [°C]
$Te_{B,i}$: Stack temperature at boilers, [°C]
Text: External ambient temperature, [°C]
P_{TE}: Gross electric active (and apparent) power at turbo-expander, [kWhe (kVArh)]
P_{CHP}: Gross electric active (and apparent) power at co-generator, [kWhe (kVArh)]
$C_{BS,k}$: Electric active (and apparent) energy for self-consumption at the substations, [kWhe (kVAhr)]
C_{TE}: Electric active (and apparent) energy for self-consumption at the turbo-expander, [kWhe (kVAhr)]
C_{CHP}: Electric active (and apparent) power self-consumption at the cogenerator, [kWhe (kVAhr)]

GE1- Non energetic parameters
$T_{gas,\ DHM}$: Tariff for natural gas consumption paid by the network manager, [€/Nm^3]
$T_{el,\ DHM}$: Tariff for the electricity consumption paid by the network manager, [€/kWhe]
$T_{gas,\ end\text{-}users}$: Tariff for natural gas consumption paid by the final end-user, [€/Nm^3]
$T_{el,\ end\text{-}user}$: Selling price of electricity produced by the network manager and sold to new end-users (if any), [€/kWhe]
$T_{th,\ end\text{-}user}$: Tariff for thermal energy consumption paid by end-users connected to the new heating system, [€/kWht]
M_{CHP}: Maintenance cost of the CHP for the district heating network manager, [€]
M_{TE}: Maintenance cost of the TE for the district heating network manager, [€]

GO1-Energetic parameters
$Q_{mix,\ DH}$: District heating production mix, [MWh and % composition]
$Q_{loss,\ DH}$: Heat loss in the network, [kWht]
C_{DH}: Electricity consumption in distribution network pumps, [kWhe]
Te_{in}, 1: Internal temperature, [°C]
Te_{in}, 2: Internal temperature, [°C]
Te_{in}, 3: Internal temperature, [°C]
Te_{in}, 4: Internal temperature, [°C]
$Q_{b,i}$: Heat flow delivered to the building, [kWht]
$C_{,i}$: Electric energy consumption of control equipment, [kWhe]

$Te_{,ext}$: External temperature, [°C]

GO1- Non energetic parameters
$T_{th, end-user}$: Tariff for thermal energy consumption paid by civil end-users connected to the new system , [€/kWht]
$T_{el, DHM}$: Tariff for the electricity consumption paid by the heat network manager, [€/kWhe]

GO2-Energetic parameters
$Q_{wg,i}$: Heat delivered to white goods, [kWht]
$Te_{in,j}$: Supply temperature, [°C]
$Te_{out,j}$: Return temperature, [°C]
$Cwg_{, j}$: Electricity use of white goods, [kWhe]
$Q_{mix, DH}$: District heating production mix, [MWh and % distribution of each thermal source]
$Q_{loss, DH}$: Heat loss in the network, [%]
C_{DH}: Electricity use in the distribution network pumps, [kWhe]

GO2- Non energetic parameters
$N_{w, j}$: Number of washes, [-]
tw: Time for a washing cycle, [Minutes]
td: Time for a drying cycle, [Minutes]
$T_{el, end-user}$: Tariff for electric energy consumption paid by the end-users, [€/kWhe]
$T_{th, end-user}$: Tariff for thermal energy consumption paid by end-users, [€/kWht]

GO3-Energetic parameters
Q_{sh}: Heat delivered to ship from the district heating system, [kWht]
V_{oil}: Oil consumption in harbour for heating purposes, [lt]
$Te_{,ext}$: Outdoor temperature, [°C]
$Q_{mix, DH}$: District heating production mix, [MWht] and % composition
$Q_{loss, DH}$: Heat loss in the network, [%]
C_{DH}: Electricity use in the distribution network pumps, [kWhe]

GO3- Non energetic parameters
$T_{el, DHM}$: Tariff for the electricity consumption paid by the district heating network manager, [€/kWhe]
$T_{th, end-user}$: Tariff for thermal energy consumption paid by the end-users connected to the new system, [€/kWht]
M: Cost of maintenance of the new system, [€]
T_{oil}: Cost of bunker oil for ship, [€/lt]

CO1-Energetic parameters
$C_{hp, i}$: Electric energy consumption of the heat pumping system, [kWhe]
C_{wp}: Electric energy consumption of the wastewater pumping system, [kWhe]
V_w: Wastewater flow rate through the heat exchanger, [Nm^3/h]
Te_w in: Inlet wastewater temperature, [°C]
Te_w, out: Outlet wastewater temperature, [°C]
$Q_{hp, i}$: Heat flow at the heat pump, [kWht]
$Q_{st-dist, j}$: Heat flow between the storage system and the distribution mine, [kWht]
$Q_{dist, m}$: Heat flow at the distribution mine, [kWht]
$G_{gas, k}$: Gas consumption, [Nm^3/h]
L_{ref}: Refrigerant losses, [lt/year]

CO1- Non energetic parameters
$T_{th, end-user}$: Tariff for thermal energy consumption paid by civil end-users (schools, swimming pool) connected to the new system, [€/kWht]
$T_{gas, end-user}$: Tariff for natural gas consumption paid by the final end-user, [€/Nm^3]
$T_{gas, DHM}$: Tariff for natural gas consumption paid by the heat network manager, [€/Nm^3]
$T_{el, DHM}$: Tariff for the electricity consumption paid by the network manager, [€/kWhe]
M: Maintenance cost for the network manager, [€]
$G_{emission, k}$: Exhausted gas flow rate (Nm^3/h) and polluting emission concentrations (CO_2, CO, NO_x, SO_x, PM, PM_{10}, $PM_{2.5}$- mg/Nm^3) by the peak load boilers serving the Celsius sub-project, [Nm^3/h]

LO1-Energetic parameters
G_{CHP}: Use of natural gas, [Nm^3/h]
P_{CHP}: Produced electricity during the event, [kWhe]
Q_{CHP}: Thermal energy produced during the event, [kWht]
Q_{DH}: Thermal energy used by the DH system during the event, [kWht]

$Q_{Loss:}$ Thermal losses during the event, [kWht]
C_{CHP}: Electricity used by the CHP out of the DH normal system, [kWhe]

LO1- Non energetic parameters
$P_{real,s}$: Real Power, [kW]
$P_{real,s\ max}$: Max Real Power, [kW]
$P_{real,s\ set}$: Real Power Point Set-Point, [kW]
$P_{reac,\ s}$: Reactive Power, [kVAr]
$P_{reac,\ s\ set}$: Reactive Power Set-Point, [kVAr]
V_s: Voltage, [Volt]
PF_s: Power Factor, [Varying from -1 to 1]
$PF_{s\ max\ +}$: Max Positive Power Factor, [Varying from 0 to1]
$PF_{s\ max\ -}$: Max negative Power Factor, [Varying from -1 to 0]
I_s: Current, [A]
$Fault_{,s}$: Major fault indications, [I/O]
DR: DR availability, [kW]
Pr_{CHP}: Real Power, [kW]
V_{CHP}: Voltage, [Volt]
I_{CHP}: Current, [A]
PF_{CHP}: Power Factor, [Varying from -1 to 1]
$P_{reac,CHP}$: Reactive Power, [kVar]

LO1-Non energetic parameters
F_{CHP}: The fee guaranteed by the Distribution Network Operator (UKPN) to the co-generator manager (BEC) during the event, [€/each event]
Fines: The fines paid by UKPN, [€]
M_{CHP}: The maintenance and operation extra-costs (paid by BEC) for the co-generator manager, [€/each event]

LO2-LO3-Energetic parameters
$C_{hp,\ A}$: Electric energy consumption of the heating pump system at the ventilation shaft, [kWhe]
$Peak_{hp,\ A}$: Peak demand, [kW]
$C_{ex,\ A}$: Electric energy consumption of the subway extraction system, [kWhe]
$Peak_{ex,\ A}$: Peak demand, [kW]
$Te_{air,IN}$: Inlet air temperature at the heat exchanger, [°C]
$Te_{air,OUT}$: Outlet air temperature at the heat exchanger, [°C]
$Q_{hp,\ A}$: Heat flow at the heat pump system, [kWht]
$Q_{he,\ A}$: Heat flow at the external heat exchanger, [kWht]
$C_{hp,\ B}$: Electric energy consumption of the heating pump system at the transformer, [kWhe]
$Peak_{hp,\ B}$: Peak demand, [kW]
$Te_{hp,\ IN}$: Oil inlet temperature at the heat pump exchanger, [°C]
$Te_{hp,\ OUT}$: Oil outlet temperature at the heat pump exchanger, [°C]
$Te_{cool,\ IN}$: Oil inlet temperature at cooling system, [°C
$Te_{cool,\ OUT}$: Oil outlet temperature at cooling system, [°C]
$V_{oil,hp,\ B}$: Oil flow rate through the heat pump exchanger, [lt/sec]
$V_{oil,cool,\ B}$: Oil flow rate through the conventional cooler, [lt/sec]
$Q_{,hp\ B}$: Heat flow at the heat pump system, [kWht]
$Q_{cool,\ B}$: Thermal energy at the transformer cooler, [kWht]
$Q_{WS,\ C}$: Thermal energy, supply side, [Nm3/h]
$Q_{WU,\ C}$: Thermal energy, user's side, [Nm3/h]
$T_{s,k}$: Temperature profile ,[°C]
$Q_{build,\ i}$: Thermal energy delivered to buildings connected to the DH in the project, [kWht]
$Q_{mix,\ DH}$: District heating production mix, [MWht and % composition]
$E_{,\ mix}$: Fuel mix, [MWh and % composition]

LO2- LO3 Non energetic parameters
$T_{th,\ end\text{-}user}$: Tariff for thermal energy consumption paid by the end-user in buildings connected to the DH system, [€/kWht]
M_A: Maintenance cost for the ventilation shaft heating pump system, [€]
M_B: Maintenance cost for the transformer heating pump system, [€]
M_C: Maintenance cost for the thermal storage system, [€]
$T_{el,\ DHM}$: Tariff for the electricity consumption paid by the network manager (DHM), [€/kWhe]

RO1-Energetic parameters
Q_{in}: Incoming thermal energy, [kWht / GJ]

Q_{out}: Outcoming thermal energy, [kWht / GJ]
C_{pump}: Electric energy consumption of buffer pump, [kWhe]
Q_{buffer}: Thermal energy in and out of the buffer, [MWh]

RO2-Energetic parameters
$Q_{WWTP,HH}/Q_{WWTP,WWTP}$: Thermal energy supplied by the heat hub to the WWTP, [kWht]
$Q_{CHP,HH}/Q_{CHP,CHP}$: Thermal energy provided by the biogas-cofired cogenerator to the heat hub, [kWht]
$Q_{Men,HH}$ / $Q_{Men,Men}$: Thermal energy provided by the heat hub to the Meneba grain processing plant, [kWht]

9GOe - Energetic parameters
$Q_{CHP:}$ Heat produced and delivered to the district heating, [MWht]
$P_{CHP:}$ Electricity produced and delivered to the grid, [MWhe]
$C_{CHP:}$ Electricity consumed internally, [MWhe]
$V_{biomass:}$ Fuel (wood chips) consumed, [kg or MWh]
$H_{biomass:}$ Energy content in fuel (wood chips), [MWh/kg] $_{9999}$
$Te_{s, DH:}$ Temperature of district heating supply [°C]
$Te_{r, DH:}$ Temperature of district heating return [°C]
$Q_{baseline:}$ Heat produced in coal boiler and delivered to the district heating before reconstruction [MWht]
$C_{baseline:}$ Coal consumed before reconstruction, [kg or MWh]
$H_{baseline:}$ Energy content in fuel (coal), [MWh/kg]
$Q_{mix,DH:}$ District heating production mix, [MWh and % composition]

9GOe- Non energetic parameters
$I_{biofuel}$: Investment cost for the conversion of old coal plant into biofuel plant in 2004, [€]
$t_{d, biofuel}$: Depreciation time of reconstruction/conversion equipment in 2004- years
I_{CHP}: Investment cost of combined heat and power equipment installed in 2010, [€]
$t_{d, CHP}$: Depreciation time of CHP equipment in 2010, [years]
$T_{wood, DHM}$: Wood chips price, [€/kg or €/MWh]
$T_{coal, DHM}$: Coal price, during the same year considered for the wood chips price (e.g., 2013) [€/kg or €/MWh]
$S_{el, DHM}$: Selling price of produced electricity- [€/MWhe]
$S_{th, DHM}$: Selling price of produced heat, [€/MWht]
O_c: Operation costs, [€/year]
M: Maintenance costs, [€/year]

29GOe- Energetic parameters
Q_{agreem}: Total thermal energy delivered by the district heating to buildings with agreements, [MWht]
$Q_{agreem, ref-i}$: Thermal energy delivered to representative buildings with agreements, [MWht]
$Q_{baseline, ref-i}$: District heating delivered to buildings before having signed the agreements, [MWht]
$Te_{indoor, ref-i}$: Indoor temperatures, [°C]
$Q_{mix,DH}$: District heating production mix, [MWh and % composition]

29GOe- Non energetic parameters
N_c: Number of customers, [Number]
A_{temp}: Total floor area of *buildings* benefitting of the climate agreements, [m^2]
$A_{temp,ref}$: Floor area of five representative buildings benefitting of the climate agreements , [m^2]
I: Investment cost of equipment necessary for control in five representative buildings, [€]
M: Operation and maintenance costs in five representative buildings, [€/year]
$t_{d,ref}$: Depreciation time in five representative buildings , [years]
Sv_{ref} : Yearly savings for energy company in five representative buildings , [€]
$T_{th, end-user}$: Tariff for thermal energy with climate agreements in five representative buildings, [€/kWht]
$T_{th, end-user, baseline:}$ Tariff for thermal energy (delivered to customer) in five representative buildings before having climate agreements, [€/kWht]

19GOe - Energetic parameters
$Q_{c, DC}$: Cooling energy delivered by absorption chillers to district cooling network,[MWht]
$Te_{s, DC}$: District cooling network supply temperature,[°C]
$Te_{r, DC}$: District cooling network return temperature,[°C]
$Te_{s, DH}$: District heating supply temperature,[°C]
$Te_{r, DH}$: District heating return temperature,[°C]
C_c: Chillers' electric energy consumption,[MWhe]
Q_{DC}: Total cooling energy produced at production facilities,[MWht]
Q'_{DC}: Total cooling energy delivered at customers substation,[MWht]
C_{DC}: Electric energy consumption of the district cooling distribution network ,[MWhe]

R: Amount of refrigerants/chemicals used,[kg]
$Q_{mix, DH}$: District heating production mix ,[MWht and % composition]
$Q_{loss,DH}$: Heat loss in the district heating network ,[%]
C_{DH}:Electric energy consumption of the district heating distribution network,[MWhe]

19GOe- Non energetic parameters
N: Number of customers connected to the cooling system,[Number]
A_{DC}: Total floor area of buildings connected to the district cooling network, [m^2]
I_c: Investment cost for absorption chillers, [€]
$t_{p,c}$: Depreciation time,[Years]
$T_{el, DCM}$: Tariff paid by the district cooling network manager (DCM) for electric energy used for absorption chillers, [€/MWhe]
$T_{th, DCM}$: Tariff paid by the district cooling network manager (DCM) for thermal energy consumption from district heating used in absorption chillers, [€/MWht]
M: Operation and maintenance costs, [€]
I_{DC}: Investment cost of district cooling network, [€]
$t_{p,DC}$: Depreciation time of district cooling network, [Years]
M: Operation and maintenance cost of district cooling network, [€]
$T_{DC, end\ user}$: Selling price of produced cold (to customer, average), [€/MWht]

11GOe- Energetic parameters
$Q_{r,DC}$: Cooling energy delivered from river water to district cooling network, [MWht]
$Te_{s, DC}$: District cooling network supply temperature, [°C]
$Te_{r, DC}$: District cooling network return temperature, [°C]
$Te_{s,river}$: Inlet temperature of river water in the heat exchangers, [°C]
$Te_{r,river}$: Outlet temperature of river water from the heat exchangers, [°C]
$C_{r,DC}$: Electric energy consumption for pumping systems for the heat exchangers, [MWhe]
Q_{DC}: Total cooling energy produced at production facilities, [MWht]
Q'_{DC}: Total cooling energy delivered at customers substations, [MWht]
C_{DC}: Electric energy consumption of the district cooling distribution network, [MWhe]

11GOe- Non energetic parameters
N: Number of customers connected to district cooling
A_{DC}: Total cooled area of buildings connected to district cooling, [m^2]
I_f: Investment cost for river water district cooling facilities, [€]
$t_{p,c}$: Depreciation time, [years]
$T_{el, DCM}$: Tariff paid for the electric energy consumptions by the district cooling network manager (DCM), [€/MWhe]
M_f: Operation and maintenance cost of river water district cooling facilities, [€]
I_{DC}: Investment cost of district cooling network, [€]
$t_{p,DC}$: Depreciation time of district cooling network, [years]
M_{DC}: Operation and maintenance cost of district cooling network,[€]
$T_{th, end\ user}$:Selling price of produced cold (to customer, average), [€/MWht]

20GOe- Energetic parameters
$Ts_{,SC}$: Supply temperature of hot water, [°C]
Q_{SC}: Heat production, [MWht]
$T_{S,DH}$: DH supply temperature, [°C]
$T_{R,DH}$: DH return temperature, [°C]
A_{coll}: Collector area, [m^2]
Dir: Direction, [(point of compass)]
Deg: Tilt angle, [°]
C: Electric energy consumption, [MWhe]

20GOe- Non energetic parameters
I: Investment costs, [€]
M: Maintenance costs, [€]
Oc: Operating costs, [€/year]
$T_{th,end-user}$: Tariff for heat consumption paid by the end-users, [€/kWht]

8GOe - Energetic parameters
Q_{inc}: Heat produced at the waste incinerator plant, [MWht]
$Q_{mix, DH}$: Total heat produced by the DH system, [MWht]
P_{inc}: Electric energy production, [MWhe]
C_{inc}: Internal consumption of electric energy, [MWhe]

V_{waste}: Amount of waste incinerated, [tons]
H_{waste}: Energy content of waste, [MWh/kg]

8GOe- Non energetic parameters
I: Investment costs, [€]
M: Maintenance costs, [€]
Oc: Operating costs (including costs/revenue for waste), [€/year]
$T_{th,end-user}$: Tariff for thermal energy consumption paid by the end-users, [€/kWht]

7GOe - Energetic parameters
$Q_{rec,DH}$: Amount of waste heat recovered at each site, [MWht]
T_{waste}: Waste heat temperature, [°C]
$Q_{mix,DH}$: Total heat production of district heating system, [MWht]
$Te_{s,DH}$: District heating supply temperature, [°C]
$Te_{r,DH}$: District heating return temperature, [°C] C_{hp}:Electric energy consumptions of the heat pumps, [MWhe]
L_{pipe}: Pipe length, [m]

7GOe - Non energetic parameters
I: Investment costs, [€]
M: Maintenance costs, [€]
Oc: Operating costs (including costs/revenue for waste), [€/year]
$F_{th, DHM}$: Fee paid by the district heating manager (DHM) for waste heat recovery, [€/MWht]
$T_{th,end-user}$: Tariff for thermal energy consumption paid by the end-users, [€/kWht]

36GOe - Energetic parameters
$Q_{f, DH}$: Thermal energy production at each facility, [MWht]
$Q_{sector, DH}$: Thermal energy delivered to customers, per sector, [MWht]
$Q_{CHP, i}$: Electric energy production at each CHP facility, [MWhe]
Te_{ext}: Outdoor temperature, [°C]
$Q_{primary, DH}$: Primary energy input at each production facility, [MWh (or other relevant unit depending on type of energy)]
$Te_{s,DH}$: District heating supply temperature, [°C]
$Te_{r,DH}$: District heating return temperature, [°C]
$C_{f, DH}$: Electric energy consumption, [*MWhe*]
L_{pipe}: Pipe length, [km]

36GOe -Non energetic parameters
$T_{th, end-user}$: Tariff for heat consumption paid by the end-users, [€/kWht]
M: Maintenance costs, [€]
O_c: Operating costs, [€]
R_{th}: Revenues from sold thermal energy for the district heating network manager, [€]
I_{yearly}: Yearly investment, [€]
N_c: Number of users/customers in different sectors, [-]

12 COe- Energetic parameters
Q_{CHP}: Thermal energy produced by the CH, [MWht]
P_{CHP} Electric energy produced by the CHP and delivered to the grid, [MWhe]
C_{CHP}: Electric energy consumed by the CHP, [MWhe];
V_{gas} : Biogas/gas consumption

12 COe- Non energetic parameters
Oc: Operating cost, [€]
Dc: Depreciation costs, [€]

6***COe- Energetic parameters***
$Qhp_{,i}$: Thermal energy produced by each heat pump, [MWht]
$Vgas_{,i}$: Gas consumption of each heat pump, [MWh]
$Chp_{,i}$: Electric energy consumption of each heat pump, [MWhe]

6COe- Non energetic parameters
Oc: Operating costs, [€]
Dc: Depreciation costs, [€]