celsius smart cities	Project Acronym: CELSIUS
	Project Title: Combined Efficiency Large Scale Integrated Urban Systems
	Grant Agreement No.: 314441
	Starting date: 01-04-2013
	Funding scheme: Collaborative project
	Project duration: 48 months

D 4.1
Report on KPI values

Delivery date	Task leader
28-02 -2014	D'Appolonia
Submission date	Prepared by:
18-03-2014	D'Appolonia
Dissemination Level	Partners
PU- Public	SP Sveriges Tekniska Forskningsinstitut, Goteborg Energy AB, Interactive Institute Swedish ICT AB, Fachhochschule Koln, Genova Reti Gas srl, UK Power Network, London Bourough of Islington, Warmtebedrijf Infra Nv, Rheinenergie

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

1. Introduction 4
2. Methodology 6
3. Specific key performance indicators - new demonstrators 8
3.1 Genoa demonstrator (GEN1) 9
3.1.1 Objective of the demonstrator and baseline situation 9
3.1.2 List of specific KPIs 11
3.2 Gothenburg demonstrator (GO1) 16
3.2.1 Objective of the demonstrator and baseline situation 16
3.2.2 List of specific KPIs 17
3.3 Gothenburg demonstrator (GO2) 19
3.3.1 Objective of the demonstrator and baseline situation 19
3.3.2 List of specific KPIs 21
3.4 Gothenburg demonstrator (GO3) 25
3.4.1 Objective of the demonstrator and baseline situation 25
3.4.2 List of specific KPIs 27
3.5 Cologne demonstrator (CO1) 30
3.5.1 Objective of the demonstrator and baseline situation 30
3.5.2 List of specific KPIs 32
3.6 London demonstrator (LO1) 36
3.6.1 Objective of the demonstrator and baseline situation 36
3.6.2 List of specific KPIs 39
3.7 London demonstrators (LO2+LO3) 42
3.7.1 Objective of the demonstrator and baseline situation 42
3.7.2 List of specific KPIs 44
3.8 Rotterdam demonstrator: RO1 48
3.8.1 Objective of the demonstrator and baseline situation 48
3.8.2 List of specific KPIs 50
3.9 Rotterdam demonstrator: RO2 52
3.9.1 Objective of the demonstrator and baseline situation 52
3.9.2 List of specific KPIs 54
4. Specific key-performance indicators: existing demonstrators 55
4.1 Gothenburg Demonstrator (9GOe) 56
4.1.1 Objective of the demonstrator and baseline situation 56
4.1.2 List of specific KPIs 56
4.2 Gothenburg Demonstrator (29GOe) 58
4.2.1 Objective of the demonstrator and baseline situation 58
4.2.2 List of specific KPIs 58
4.3 Gothenburg Demonstrator (19GOe) 60
4.3.1 Objective of the demonstrator and baseline situation 60
4.3.2 List of specific KPIs 60
4.4 Gothenburg Demonstrator (11GOe) 63
4.4.1 Objective of the demonstrator and baseline situation 63
4.4.2 List of specific KPIs 63
4.5 Gothenburg Demonstrator (20GOe) 66
4.5.1 Objective of the demonstrator and baseline situation 66
4.5.2 List of specific KPIs 66
4.6 Gothenburg Demonstrator (8GOe) 67
4.6.1 Objective of the demonstrator and baseline situation 67
4.6.2 List of specific KPIs 67
4.7 Gothenburg Demonstrator (7GOe) 68
4.7.1 Objective of the demonstrator and baseline situation 68
4.7.2 List of specific KPIs 68
4.8 Gothenburg Demonstrator (36GOe) 69

4.8.1 Objective of the demonstrator and baseline situation 69
4.8.2 List of specific KPIs 69
4.9 Cologne Demonstrator (12COe) 72
4.9.1 List of specific KPIs 72
4.10 Cologne Demonstrator (6COe) 74
4.10.1 List of specific KPIs 74
5. General KPIs 75
5.1 Energy indicators 75
5.2 Environmental indicators 76
5.3 Economic indicators 77
5.4 Social indicators 77
6. Conclusions 82

1. Introduction

The Celsius project aims at developing, optimizing and promoting efficient decentralized heating and cooling systems in cities thus 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 heat 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 identification code in the Celsius project 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	Thermo solar plants for heating
36GOe	Gothenburg	Total production and distribution system
19GOe	Gothenburg	Absorbtion 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 district heating system
17ROe	Rotterdam	Cooling by river water
5ROe, 14ROe	Rotterdam	Vertical city

Table 2 - Existing demonstrators in the Celsius project

The overall aim of this report is to present the sets of key performance indicators (KPIs) that have been set-up in the framework of task 4.1 in order evaluate the different impacts of the Celsius demonstration projects on track.
Since the Celsius project aims to be a corner stone in the large scale deployment of smart cities, monitoring the performance of the different demonstrators is essential in evaluating the transfer and replication potential in different European regions.
Hence, relevant economic, energetic, environmental and social performance indicators (KPIs) have been identified at two different levels:

- Specific KPIs, taking into account peculiar features of each demonstrator included in the framework of the Celsius project;
- Generic KPIs, aimed at identifying common aspects covering all the demonstrators involved in the Celsius project.

The document is divided into three different parts, each covering specific aspects related to the identification of key-performance indicators:

- Methodology: in this part, the approach followed for the KPIs identification has been detailed by providing an in-depth description of the methodology applied for the quantitative analysis both at specific and at a general level;
- Specific case analysis: in this part, each demonstrator has been analyzed by identifying specific tailored performance indicators aimed at progressively evaluating the

technical, environmental, economic and social performances in comparison with the identified business as usual situation;
- Identification of common features: the last part of the document analyzes the common aspects of Celsius demonstrators by providing a set of general KPIs that will be used for the evaluation of the global impact of the Celsius project.

2. Methodology

The set-up of tailored key performance indicators is a useful approach to provide a quantitative measurement of the performance of the Celsius demonstrators during their operation in order to:

- guarantee transparency and consistency of monitoring procedures;
- evaluate the achievement of the prefixed targets by identifying possible deviations and strategies for improvement;
- compare the application of the innovative developed concepts with the respective business as usual situations;
- compare different technical solutions among them;
- communicate in a simple and understandable way the achievements related to the operation of each demonstrator to the involved stakeholders, public authorities, end-users and people benefitting of the application of the new technologies, increasing public awareness and acceptance at different levels and potential of replicability in similar contexts.

The identification of KPIs has required the set-up of a proper methodology that has been followed in the framework of the Celsius project, consisting of different working phases described below:

- Analysis of the concept of each demonstrator: in particular, each demonstrator responsible partner has been interviewed in order to collect information on the objectives of the demonstrator, on the specific smart technology applied for reaching the objective, on the integration of the process with possible existing facilities, on the expected impact and on the relative reference context;
- Identification of the baseline situation: the business as usual situation has been identified for each demonstrator, aimed at defining a reference scenario toward which to 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 a list of specific KPIs: a list of specific technical, environmental, economic and social KPIs has been identified and shared with each demonstrator responsible partner in order to ensure the convergence of the elaborated list to the real implemented project and to the specific context;
- Definition of common conventions and methodology for calculation of specific KPIs: a common nomenclature scheme has been set-up for the defined KPIs in order to harmonize the identification of the specific KPIs. In particular, an ID code has been provided to each

indicator with a specific section indicating the name of the demonstrator, the typology of KPI (technical, economic, energetic and social) and a progressive number for distinction as reported in the figure 1.
Moreover, when useful, for each specific KPI a methodology of calculation has been set-up in order to provide consistent and transparent formula for the evaluation of the performance during the operation of the demonstrators. The reported formula are the mathematical combination of parameters monitored during the operation of the demonstrators as defined in the deliverable 4.2 (Common monitoring methodology) with data/parameters which will be collected for the evaluation of the baseline situation.

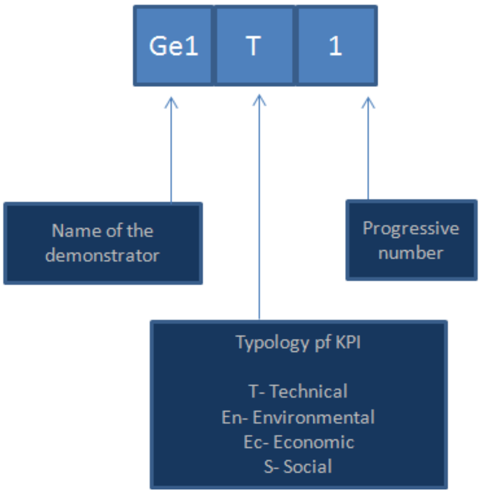

Figure 1: *ID-code example for specific KPIs*

- Definition of a list of generic KPIs: the different analyses performed on each demonstrator for the identification of specific KPIs have been combined in order to define common features to all the demonstrators following a bottom-up approach aimed at providing general indicators that can be representative of the Celsius City concept and vision increasing the potential for replication of the developed model.

3. Specific key performance indicators - new demonstrators

Following the specific analysis performed on each demonstrator, a list of specific KPIs has been set-up in order to evaluate the performance and the impact of each demonstrator from the technical, economic, social and environmental point of view. KPIs have been shared with each demonstrator responsible partner in order to verify the suitability of the identified indicators to the specific context in which the demonstrator is applied.

An iterative working approach has been followed, by establishing periodical contacts with project partners, collecting their feedback on the preliminary provided lists and progressively implementing updated information in order to ensure the convergence of the elaborated list both to the real implemented technical solution and to the specific context.

Considering the different degrees of implementation of the various demonstrators at the present moment, the list of suggested KPIs can be subject to possible modifications/integrations in the future in accordance with the definitive design and real implementation of each applied technical solution. Specific KPIs calculation will be based on the results of monitored parameters measurements which will be collected every six months during the operation of the demonstrator as described in the deliverable 4.2. The results from the analysis will be included in the progressive deliverables 4.3 “Reports detailing progress and achievements on each demonstrator and analyzing causes for deviation”.

In the sub-paragraphs below, the analysis of each new demonstrator to be realized and operated in the framework of the Celsius project is reported by including a description of the implemented technology and of the correspondent baseline situation, a simplified layout of the technical solution, the list of relevant specific KPIs and a summary table including, when necessary, the respective formulas for calculation.

For each demonstrator four categories of specific indicators have been identified:

- *Technical indicators*, aimed at evaluating the energy efficiency of the demonstrators during the operation;
- *Economic indicators*, providing the evaluation of the economic impact for the involved stakeholders and main end-users;
- *Environmental indicators*, providing estimations of the environmental impact deriving from the implementation of the demonstrator;
- *Social indicators*, aimed at estimating the main measurable social benefits due to the application of the technology.

3.1 Genoa demonstrator (GEN1)

3.1.1 Objective of the demonstrator and baseline situation

Along with energy saving and efficiency improvement actions, a more widespread use of distributed generation and district heating/cooling is planned by Genoa City administration.
Distributed generation is being in fact considered as a key-element for the diversification of the energy supply mix, and one of the promising potentials on which the city administration plans to intervene in order to achieve the intended targets for 2020. A more widespread use of distributed generation would allow shifting from the actual widespread use of low efficiency independent heating systems to higher efficiency solutions, thus reducing significantly overall fuel consumptions and CO_2 emissions. Thus, in order to increase energy efficiency within an important area of the city of Genoa, the Val Bisagno area, the development of a local energy system integrating the industrial area is currently being planned.
In this specific context, the objective associated to Genoa's demonstrator "Energy Recovery from the natural gas distribution network" (GE1) is to increase the overall energy efficiency associated to the gas distribution activity. In order to achieve the objective, the installation of an expansion turbine interfaced to a gas fired CHP plant is foreseen. Thus, it will be possible to recover both the mechanical energy from the gas expansion process and heat from co-generation, servicing a small heating network that will supply several buildings inside and outside the industrial park (Gavette district). The industrial area where the demonstrator will be built hosts the natural gas distribution facilities, where the gas pressure is reduced from 24 bars of the national transmission network to the 5 bar of the local distribution. The actual plan foresees the installation of a turbo-expander able to recover the mechanical energy inherent in the pressurized natural gas (currently wasted within a standard lamination process) in order to generate electric energy. The expansion turbine will directly produce electric energy. Expansion with mechanical energy recovery is a process that needs heat to compensate temperature drop of gas, thus heat is needed. Heat will be provided by a gas-fired CHP. The CHP plant will also serve a small heating network, providing heat to buildings inside the industrial park as well as the firefighter's station outside of it.
The baseline situation identified for the specific GE1 case is referred to a standard lamination process where mechanical energy inherent in the pressurized gas (24 bar) is wasted and heat to the final end-users is supplied by means of independent gas-fired boilers. In particular, baseline situation can be detailed by referring to the two main implemented equipments (expansion turbine and CHP):

- without the realization of the expansion turbine, mechanical energy inherent in the pressurized natural is wasted within a standard lamination process; thus, electricity required by the district is generated by the traditional mix of Italian electric grid;

- without the gas fired CHP plant and the related heating network foreseen for the surrounding Gavette district, heat from the gas expansion process is wasted and heat is supplied by means of independent gas-fired boilers.

A simplified layout of the process is reported in the figure below.

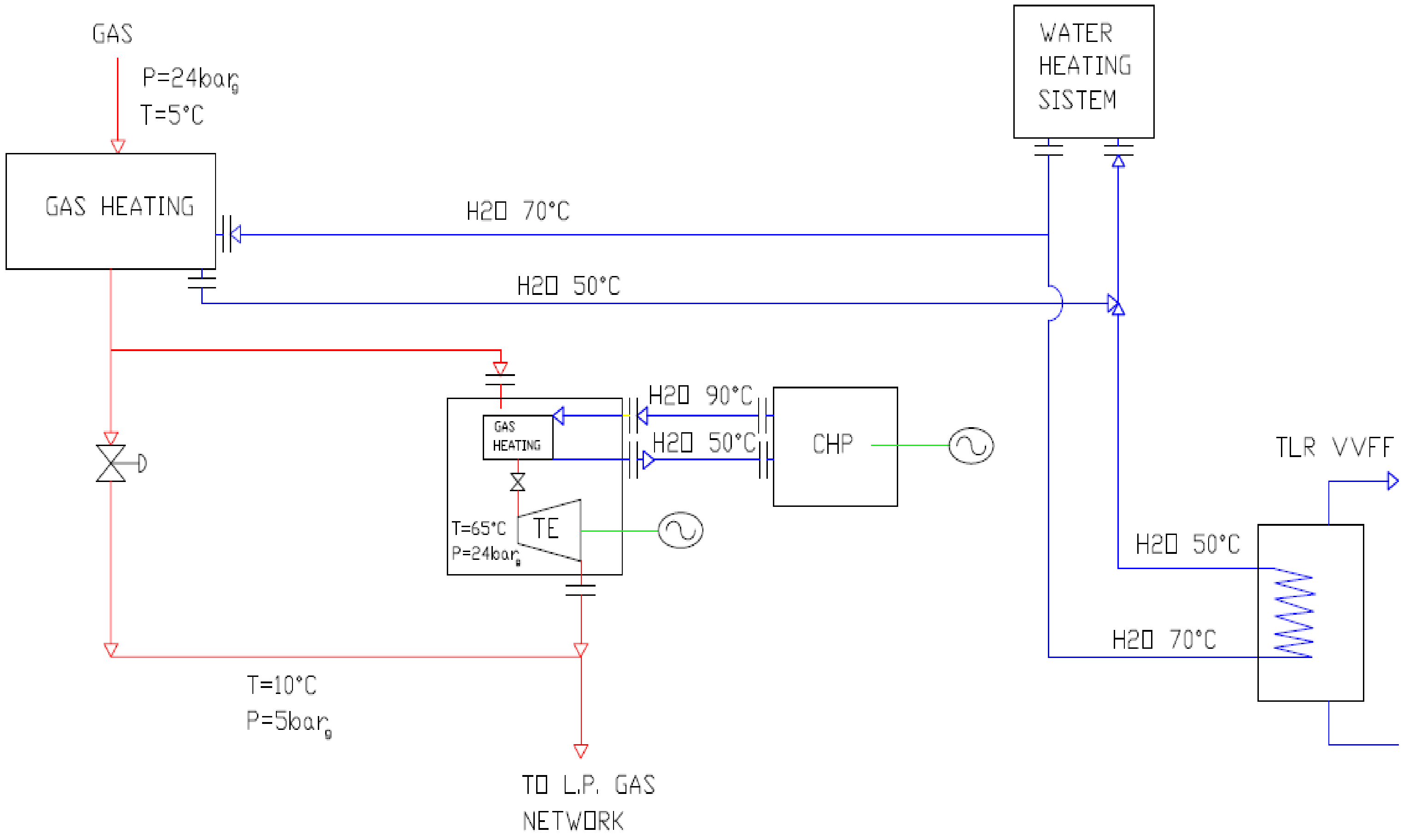

Figure 2: *GE1 simplified layout*

3.1.2 *List of specific KPIs*

Technical KPIs

- Ratio between the gas flow rate through the turbo-expander and the gas flow rate through the lamination valve;
- Yearly amount of net electric energy produced by the turbo-expander- *MWhe/year;*
- Yearly amount of net electric energy produced by the CHP system- *MWhe/year;*
- Yearly produced net electric energy- *MWhe/year;*
- Amount of thermal energy produced by the CHP – *MWht/year;*
- Amount of thermal energy provided by the district heating- *MWht/year;*
- Ratio between the yearly amount of thermal energy used for gas heating and the yearly amount of thermal energy produced by the CHP;
- Ratio between the yearly amount of thermal energy used in the district heating network and the yearly amount of produced thermal energy;

Environmental KPIs

- Variation of emissions for the main considered pollutants connected to the electric energy production compared with the baseline situation (kg/year of saved PM_{10}, $PM_{2.5}$, TSP, NO_x, SO_x, CO, CO_2);
- Variation of emissions for the main considered pollutants connected to the thermal energy production compared with the baseline situation (kg/year or kg/kWh of saved PM_{10}, $PM_{2.5}$, TSP, NO_x, SO_x, CO, CO_2);
- Yearly GHG savings (kg/year of saved CO2e and % of reduction).

Economic KPIs

- Yearly savings generated by self-production of electric energy with reference to baseline situation- *€/year*;
- Yearly savings arising from the implementation of district heating network with reference to baseline situation- *€/year;*
- Yearly cost of gas burnt in the CHP- *€/year;*
- Yearly cost of gas burnt in the boilers- *€/year;*
- Cost of maintenance of the turbo-expander per each kWh of net produced electric energy- *€/year;*
- Cost of maintenance of the CHP per each kWh of net produced electric energy- *€/kWhe;*
- Yearly cost of maintenance of the entire system- *€/year;*
- The reduction in the bill for end-users *€/kWht.*

Social KPIs

- Number of working hours used for running and maintaining the TE-CHP system- *hours/year;*
- Number of working hours used for running and maintaining the district heating system- *hours/year;*
- Number and type of possible complaints (e.g. for noise) by the citizens living in the neighbourhood.

ID	KPI	Unit of Measurement	Formula	Comments
GE1T1	Ratio between the gas flow rate through the turbo-expander and the gas flow rate through the lamination valve	-	$\frac{G_{TE}}{G_{LV}}$	This indicator will be estimated as an average value on a six month average period
GE1T2	Yearly amount of net electric energy produced by the turbo-expander	*MWhe/year*	$\sum_{year}(P_{TE} - C_{TE})$	-
GE1T3	Yearly amount of net electric energy produced by the CHP system	*MWhe/year*	$\sum_{year}(P_{CHP} - C_{CHP})$	-
GE1T4	Total produced net electric energy	*MWhe/year*	$GE1T2 + GE1T3$	-
GE1T5	Yearly amount of thermal energy produced by the CHP	*MWht/year*	$\sum_{year} Q_{CHP}$	-
GE1T6	Yearly amount of thermal energy provided by the district heating	*MWht/year*	$\sum_{year} \sum_{j} Q_{DH,j}$	-
GE1T7	Ratio between the yearly amount of thermal energy used for gas heating before the expansion in turbine and the yearly amount of thermal energy produced by the CHP	-	$\frac{\sum_{year} Q_{TE}}{\sum_{year} Q_{CHP}}$	-
GE1T8	Ratio between the yearly amount of thermal energy provided by the district heating network and the yearly amount of thermal energy produced by the CHP	-	$\frac{\sum_{year} \sum_{j} Q_{DH,j}}{\sum_{year} Q_{CHP}}$	-

Table 1- Technical KPIs (GE1)

ID	KPI	Unit of Measurement	Formula	Comments
GE1En1	Variation of emissions for the main considered pollutants connected to the electric energy production compared with the baseline situation	*Kg/year of saved TSP, NOx, CO, CO_2*	$\sum_{year} E_{el\,grid} \cdot GE1T4 - E_{el\,CHP} \cdot P_{CHP} - E_{el\ \ TE} \cdot P_{TE} - E_{th\ CHP} \cdot Q_{TE}$	The calculation will take into account the specific emission factors ($E_{el\ grid}$) for each pollutant based on the average Italian electric grid emissions in order to estimate emissions referred to the baseline situation. Savings must be reduced by taking into account specific emissions related to the operation of the CHP (Eel $_{CHP}$ is the emission factor related to the electric energy production from the CHP), to the operation of the TE (Eel $_{TE}$ is the emission factor related to the electric energy production from the TE) as well as the emissions associated to the thermal energy produced by the CHP which is mainly used for the pre-heating of the gas before the expansion in turbine. Different splitting of the CHP contribution to the emissions related to the thermal and electric energy production will be evaluated in the future based on how the CHP will be concretely operated (for gas pre-heating and for heat supply to district heating). The specific emission factors will be derived from periodical controls for the CHP (if available), from specific nameplates of the equipments and/or available data provided by the demo responsible partners
GE1En2	Variation of emissions for the main considered pollutants connected to the thermal energy production compared with the baseline situation	*Kg/year of saved TSP, NOx, CO, CO_2*	$E_{boiler} \cdot \sum_{year} \sum_{i} G_{B\,i,baseline} - E_{boiler} \cdot \sum_{year} \sum_{i} G_{B\,i,}$	E_{boiler} is the specific emission factors for each pollutant associated to existing gas boilers that will be derived from periodical controls, from specific nameplates of the equipments and/or available data provided by the demo responsible partners
GE1En3	Yearly GHG savings	*kg/year of saved CO_2e*		GHG emission will be calculated by applying specific conversion factors to greenhouse gas for the conversion into kg CO_{2e}

Table 2- Environmental KPIs (GE1)

ID	KPI	Unit of Measurement	Formula	Comments
GE1Ec1	Yearly savings generated by self-production of electric energy with reference to baseline situation;	€/year	$GE1T4 \cdot (T_{el,DHM} - Pcost_{el})$	$P_{cost,el}$ is the production cost of produced electric energy and it will be evaluated based on the new investment costs, operating costs and maintenance costs
GE1Ec2	Yearly cost for natural gas burnt in the CHP	€/year	$\sum_{year} G_{CHP} \cdot T_{gas,DHM_{CHP}}$	-
GE1Ec3	Yearly cost for natural gas burnt in boilers	€/year	$\sum_{year} \sum_{i} G_{boiler,i} \cdot T_{gas,DHM}$	-
GE1Ec4	Savings arising from the reduction of natural gas consumption	€/year	$\sum_{year} G_{baseline} \cdot T_{gas,DHM} - GE1Ec2 - GE1Ec3$	$G_{baseline}$ is the natural gas consumption in gas boilers in the baseline situation
GE1Ec5	Cost of maintenance of the turbo-expander per each kWh of net produced electric energy	€/kWhe	$\frac{\sum_{year} M_{TE}}{GE1T2}$	-
GE1Ec6	Cost of maintenance of the CHP per each kWh of net produced electric energy	€/kWhe	$\frac{\sum_{year} M_{CHP}}{GE1T3}$	-
GE1Ec7	Yearly cost of maintenance of the entire system	€/year	$\sum_{year} M_{CHP} + \sum_{year} M_{TE}$	-
GE1Ec8	Variation in the bill for end-users for thermal energy consumption	€/kWh	$T_{th,end-user} - T_{th,end-user\,baseline}$	$T_{th,end-user baseline}$ is the tariff for thermal energy consumption paid by the end-user in the baseline situation

Table 3- Economic KPIs (GE1)

ID	KPI	Unit of Measurement
GE1S1	Number of working hours used for running and maintaining the TE-CHP system	*hours/year*
GE1S3	Number and type of possible complaints (e.g. for noise) by the citizens living in the neighbourhood	-
GE1S4	Number of additional end-users benefitting of the implementation of the new system	-

Table 4- Social KPIs (GE1)

3.2 Gothenburg demonstrator (GO1)

3.2.1 Objective of the demonstrator and baseline situation

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 but 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 to the new system, corresponding to approximately 75,000 m^2 of living area.

In this case, the baseline situation is referred to the same buildings without the implementation of the active heat load control.

A simplified layout is reported in the figure below.

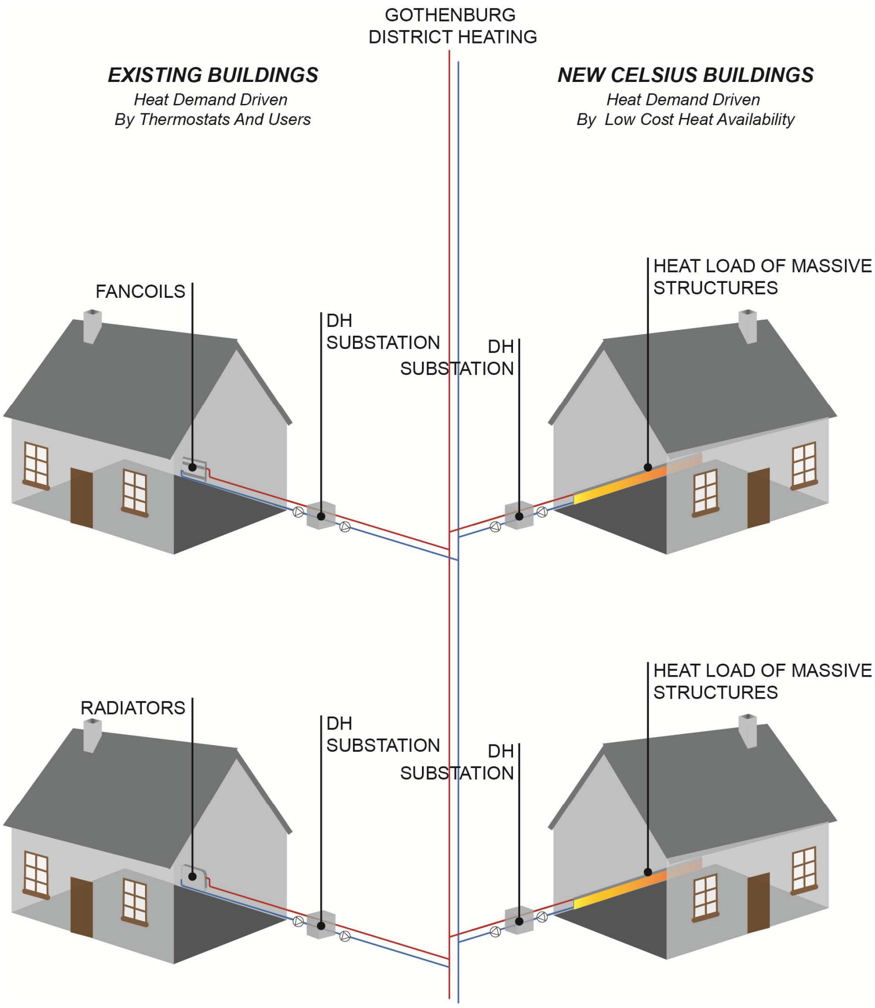

Figure 3: *GO1 simplified layout*

3.2.2 *List of specific KPIs*

Technical KPIs

- Yearly heat demand- *kWh/m²;*
- Change in yearly heat demand in comparison with baseline situation- *kWh/m²;*
- Peak load reduction- *kW;*
- Average indoor temperature (seasonal average)- *°C;*
- Change of average indoor temperature with reference to baseline situation- *°C;*
- Variation of indoor temperature- *°C* ;
- Change of variation of indoor temperature in comparison with baseline situation- *°C;*
- Average outdoor temperature- *°C.*

Concerning economic, social and environmental KPIs, generic KPIs defined in chapter 5 will be considered sufficient for summarizing GO1 achievements.

ID	KPI	Unit of Measurement	Formula	Comments
GO1T1	Yearly heat demand	$kWh/m^2\ year$	$\sum_{year} \sum_i Q_{b,i} / A_{tot}$	
GO1T2	Change in yearly heat demand in comparison with baseline situation	$kWh/m^2 year$	$GOT1 - Q_{baseline}$	$Q_{baseline}$ is the correspondent heat demand describing the baseline situation
GO1T3	Peak load reduction	kW		Calculation will be performed by taking into account the peak load in the baseline situation and in the current situation (average of daily peaks in the season)
GO1T4	Average indoor temperature (seasonal average)	$°C$	$\frac{\sum_{season} Te_{in}(h)}{hours_{season}}$	
GO1T5	Change of average indoor temperature with reference to baseline situation	$°C$	$GOT4 - Te_{in,baseline}$	$Te_{in\ baseline}$ is the average indoor temperature in the baseline situation
GO1T6	Variation of indoor temperature	$°C$	$\sigma(Te_{in})$	Standard deviation of indoor temperature
GO1T7	Change of variation of indoor temperature in comparison with baseline situation	$°C$	$\sigma(Te_{in}) - \sigma(Te_{in,baseline})$	
GO1T8	Average outdoor temperature	$°C$	$\frac{\sum_{season} Te_{ext}(h)}{hours_{season}}$	

Table 5- Technical KPIs (GO1)

3.3 Gothenburg demonstrator (GO2)

3.3.1 Objective of the demonstrator and baseline situation

The overall objective of this demonstrator is to install 300 innovative white goods (i.e. dishwashers, washing machines and dryers) using low-grade energy (district heating hot water), replacing conventional machines typically using high-grade electric energy both for running the moving parts and for heating purposes.

The machines are connected to district heating supply, independently from heat and domestic hot water supply and their installation is planned in laundry rooms of residential multi-family buildings as well as in other typology of buildings (i.e., sport facilities).

The machines have been developed by ASKO CLINDA and were recently introduced on the market. Preliminary tests have been performed on the new machines (washing machines and dryers) in order to evaluate the performance from the energetic point of view, showing a high rate of replacement of electric energy compared with conventional machines (about 75% of electric energy has been replaced by district heating hot water). Nevertheless, a long term monitoring of a higher number of machines, differentiated on the basis of different type of buildings and of installed white goods is necessary to assess results on performances of the applied technology from the energetic, environmental, economic and social point of view.

As baseline situation, the same type of laundry rooms with standard and new white goods using only electric energy (also for heating purposes) will be taken into account in order to evaluate the efficiency of the new machines in comparison with conventional systems.

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

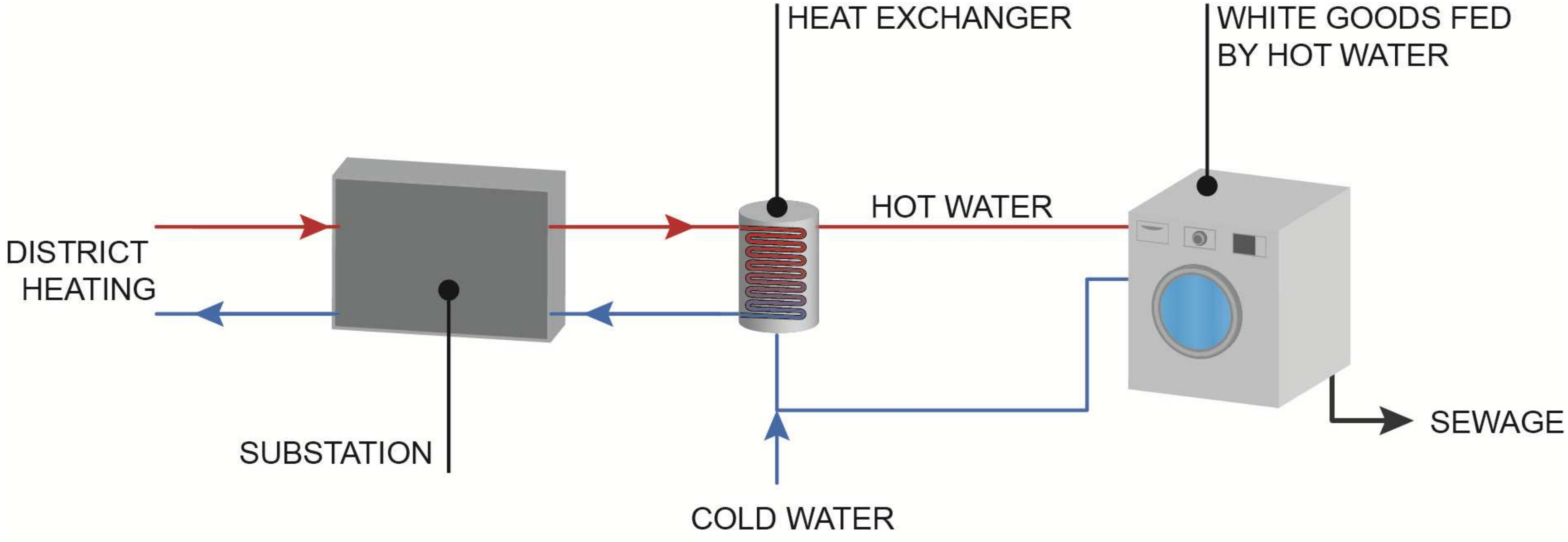

Figure 4: *GO2 simplified layout*

3.3.2 List of specific KPIs

Technical KPIs

- Yearly heat demand per laundry room- *kWht/year laundry room*;
- Yearly electric energy savings per laundry room- *kWhe/year laundry room*;
- Percentage of substituted electric energy with reference to the baseline situation- *%*;
- Heat demand per washing cycle- *kWht/washing cycle*;
- Electric energy savings per washing cycle- *kWhe/washing cycle.*

Environmental KPIs

- Yearly pollutant emissions and GHG savings due to the reduction of electric energy consumption in comparison with the baseline situation- *kg/year*;
- Pollutant emissions and GHG savings per wash due to the reduction of electric energy consumption in comparison with the baseline situation- *kg/wash.*

Economic KPIs

- Economic savings per washing cycle- *€/washing cycle*;
- Economic savings per year- *€/year*;
- Payback of the extra investment- *years.*

Social KPIs

- Time savings per wash- *minutes*;
- Number of residents/users benefitting of the new investment.

ID	KPI	Unit of Measurement	Formula	Comments
GO2T1	Yearly heat demand per laundry room	*kWht/year laundry room*	$\sum_{year} \sum_{i} Q_{wg,i}$	-
GO2T2	Yearly electric energy savings per laundry room	*kWhe/year laundry room*	$\sum_{year} \sum_{i} C_{wg,i} - \sum_{year} \sum_{i} C_{wg,i-baseline}$	-
GO2T3	Percentage of substituted electric energy with reference to baseline situation	*%*	$\frac{C_{wg,i-baseline} - C_{wg,i}}{C_{wg,i-baseline}}$	Average values of electric consumption for the different machines will be considered. $C_{wg,i\text{-baseline}}$ is the electric energy consumption of the traditional machine in similar laundry rooms (baseline situation).
GO2T4	Heat demand per washing cycle	*kWht/wash*	$\frac{GO2T1}{\sum_{year} \sum_{i} N_{i}}$	Each typology of white good will be considered (washing machines, dryers, dish washers). N_i is the number of yearly washing cycles per typology of white good and per laundry room.
GO2T5	Electric energy savings per washing cycle	*kWhe/wash*	$\frac{GO2T2}{\sum_{year} \sum_{i} N_{i}}$	Each typology of white good will be considered (washing machines, dryers, dish washers).

Table 6- Technical KPIs (GO2)

ID	KPI	Unit of Measurement	Formula	Comments
GO2En1	Yearly pollutant emissions and GHG savings due to the reduction of electric energy consumption in comparison with the baseline situation	*kg/year of saved CO_2e laundry room*	$E_{el_{grid}} \cdot GO2T2 - E_{DHmix} \cdot GO2T1$	Emissions savings will be calculated by taking into account the savings deriving from the substitution of electric energy with low temperature district heating. The calculation will take into account the specific emission factors ($E_{el\ grid}$) for each pollutant based on average electricity grid in Sweden as well as the emission factor for each pollutant (E_{DHmix}) associated to the district heating mix replacing the use of electric energy in the machines. GHG emission will be calculated by applying specific conversion factors to greenhouse gas emission for their conversion into kg CO2e
GO2En2	Pollutant emissions and GHG savings per wash due to the reduction of electric energy consumption in comparison with the baseline situation	*kg of saved CO_2e/wash*	$E_{el_{grid}} \cdot GO2T5 - E_{DHmix} \cdot GO2T1$	

Table 7- Environmental KPIs (GO2) of

ID	KPI	Unit of Measurement	Formula	Comments
GO2Ec1	Economic savings per washing cycle	*€/wash*	$GO2T5 \cdot T_{el,end-user} - GO2T4 \cdot T_{th,end-user}$	-
GO2Ec2	Economic savings per year	*€/year*	$\sum_{year} Q_{wg,i} \cdot T_{el,end-user} - \sum_{year} Q_{wg,i} \cdot T_{th,end-user}$	-
GO2Ec3	Payback of the extra investment	*Years*	-	Based on investment costs for the extra investment, operating costs and estimated economic savings

Table 8- Economic KPIs (GO2)

ID	KPI	Unit of Measurement
GO2S1	Time savings per wash	*minutes*
GO2S2	Number of residents/users benefitting of the new investment	-

Table 9- Social KPIs (GO2)

3.4 Gothenburg demonstrator (GO3)

3.4.1 Objective of the demonstrator and baseline situation

Traditionally, when a ship is at quay, electrical generators and heating equipments are needed to be run, usually consuming bunker oil. In Gothenburg there are already possibilities to connect ships at quay to the electrical grid while heating equipments on board, i.e. oil fired boilers, still need to be used. The objective of the GO3 demonstrator is to connect ships at quay in Gothenburg to the district heating in order to reduce the consumption of bunker oils, by consequently decreasing the emissions level and contributing to the improvement of air quality in the city.

In this demonstrator, one ship will be connected to the district heating network through:

- The adaptation of ship to receive district heating (connections, heat exchangers etc.);
- The installation and connection of a flexible connection at quay, for the supply of district heating hot water.

As baseline situation, the same ship, using standard oil fired boilers for heating purposes at quay, will be considered in order to evaluate the impact of the demonstrator in comparison with the conventional situation.

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

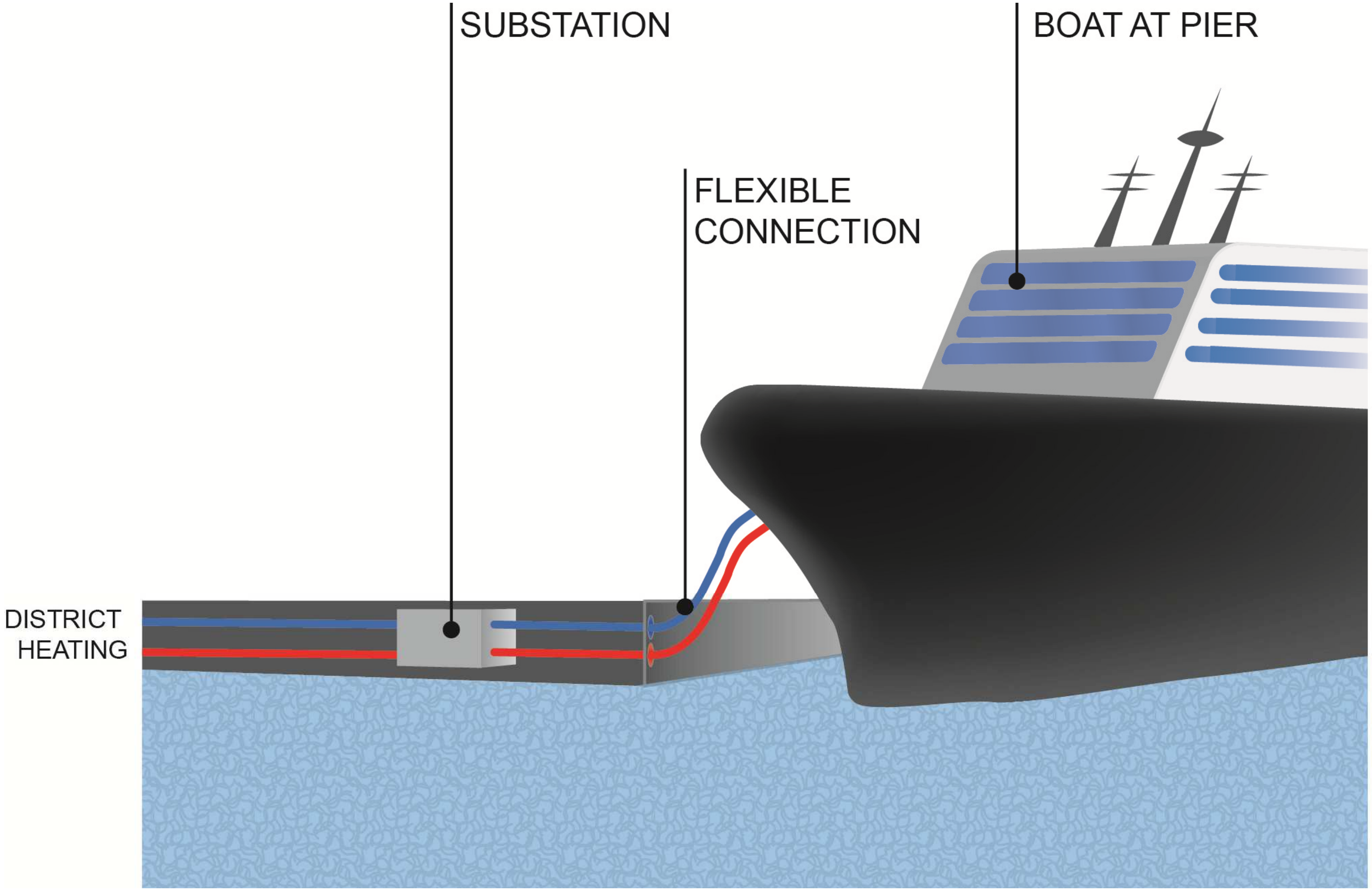

Figure 5: *GO3 simplified layout*

celsius smart cities

3.4.2 *List of specific KPIs*

Technical KPIs

- Yearly thermal energy delivered to ship in harbour- *MWht/year;*
- Change in yearly use of oil at quay in comparison with the baseline situation- *lt/year.*

Environmental KPIs

- Savings of PM10, PM2.5, TSP, NOx, SOx, CO, CO_2 with reference to the baseline emission- *kg/year;*
- GHG savings connected to the reduction of oil use with reference to the baseline situation (*kg/year of saved CO_2e* and ratio between the reduction and the baseline emissions).

Economic KPIs

- Economic savings per year due to reduction of oil consumption- *€/year;*
- Payback of the extra investment- *years.*

Social KPIs

- Reduction of complaints for noise with reference to baseline situation;
- The number of working hours used for running and maintaining the system- *hours/year.*

ID	KPI	Unit of Measurement	Formula	Comments
GO3T1	Yearly thermal energy delivered to ship in harbour	*MWht/year*	$\sum_{year} Q_{sh}$	-
GO3T2	Change in yearly use of oil at quay in comparison with the baseline situation	*lt/year*	$\frac{\sum_{year}\left(V_{oil,baseline} - V_{oil}\right)}{\sum_{year} V_{oil,baseline}}$	$V_{oil\ baseline}$ is the oil consumption in boilers in the baseline situation

Table 10- Technical KPIs (GO3)

ID	KPI	Unit of Measurement	Formula	Comments
GO3Ec1	Economic savings per year due to reduction of oil consumption	*€/year*	$\sum_{year}\left(V_{oil,baseline} - V_{oil}\right)\cdot T_{oil} - GO3T1 \cdot T_{th,end-user}$	
GO3Ec2	Payback of the extra investment	*years*		Calculation will be performed based on investment costs for the extra investment, operating costs, maintenance costs and estimated economic savings

Table 11- Economic KPIs (GO3)

ID	KPI	Unit of Measurement	Formula	Comments
GO3En1	kg/year of saved PM_{10}, $PM_{2.5}$, TSP, NO_x, SO_x, CO, CO_2 with reference to the baseline situation	*kg/year*	$\sum_{year}\left(V_{oil,baseline} - V_{oil}\right)\cdot E_{oil-boiler} - GO3T1 \cdot E_{DHmix}$	$E_{oil-boiler}$ is the emission factor for each pollutant associated to the consumption of bunker oil in the boilers. E_{DHmix} is the estimated emission factor for each pollutant associated to the district heating mix replacing the use of bunker oil in boilers.
GO3En2	GHG savings connected to the reduction of oil use with reference to the baseline situation (kg/year of saved CO_2e and ratio between the reduction and the baseline emissions)	*kg/year*	-	GHG emission will be calculated by applying specific conversion factors in order to convert greenhouse gas emissions into kg of CO_2 equivalent

Table 12- Environmental KPIs (GO3)

ID	KPI	Unit of Measurement
GO3S1	Reduction of complaints for noise with reference to baseline situation	-
GO3S2	The number of working hours used for running and maintaining the system	*hours/year*

Table 13- Social KPIs (GO3)

3.5 Cologne demonstrator (CO1)

3.5.1 Objective of the demonstrator and baseline situation

The main objective of this demonstrator is to overcome technical and economic barriers to recover heat from sewage network and use it in decentralized local heating network by supplying heat to local school buildings. The demonstrator foresees the application of this technology in three different spots of the city, with different conditions of the supply side on one hand and similar end-users (school buildings) on the other hand.

In particular:

- *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 and 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.

The baseline situation that will be taken into account is referred to the utilization of gas fired condensing boilers as the sole equipment for supplying heat to the same schools. A simplified layout of the demonstrator is reported in the figure below.

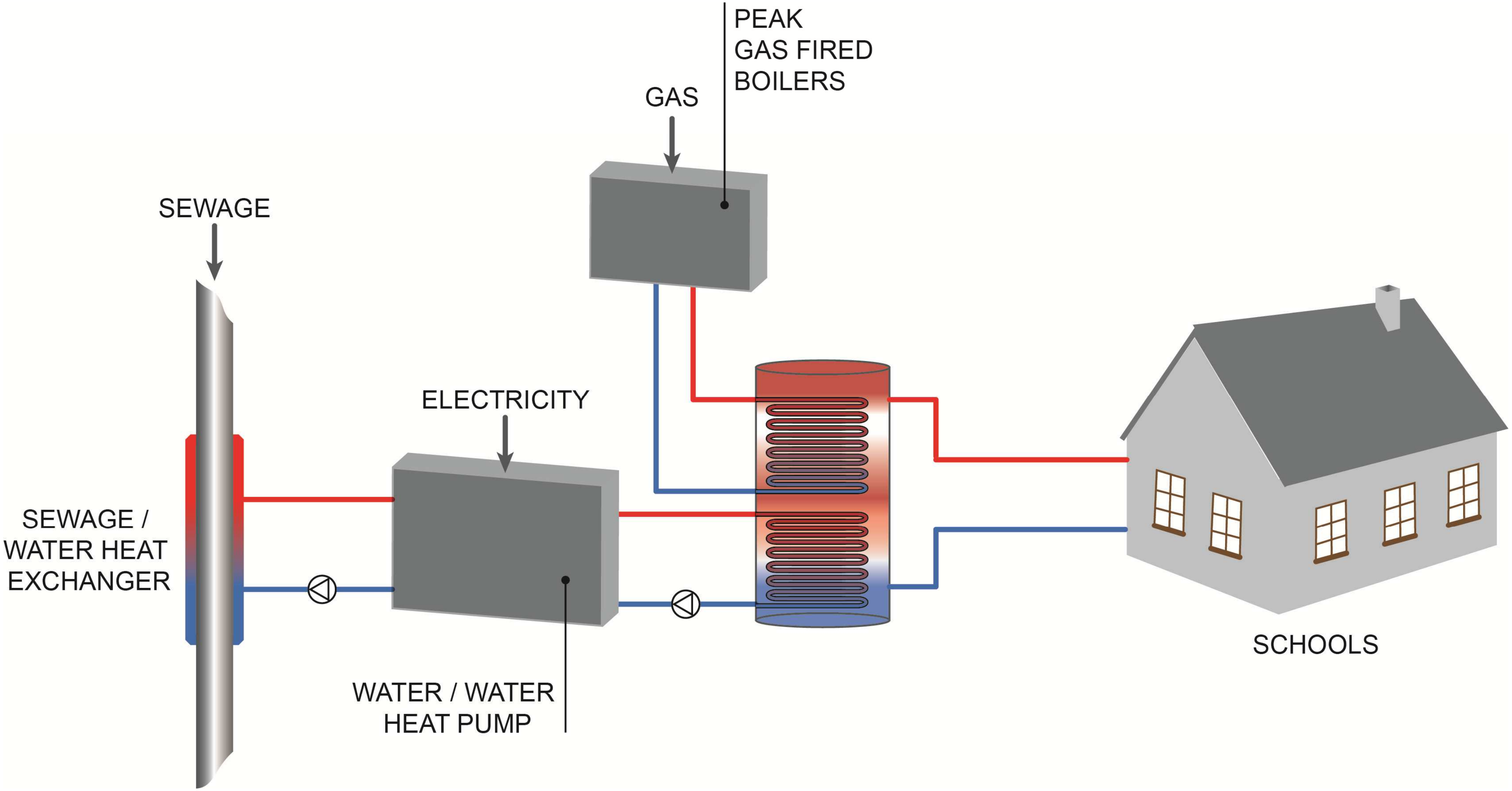

Figure 6: *CO1 simplified layout*

3.5.2 *List of specific KPIs*

Technical KPIs

- Energy efficiency at each spot, defined as the ratio between heat produced at each spot and primary energy consumption;
- Seasonal COP for each heat pump system;
- Variation of primary energy in comparison with the baseline situation at each spot;
- Energy efficiency variation in comparison with the baseline situation at each spot.

Environmental KPIs

- Variation of pollutant emissions with reference to baseline situation at each spot (*kg/year* of saved PM_{10}, $PM_{2.5}$, TSP, NO_x, SO_x, CO, CO_2);
- Yearly GHG savings at each spot with reference to baseline situation- *kg/year of saved* CO_2e *and % of variation.*

Economic KPIs

- Yearly operational cost per kWh of thermal energy supplied at each spot-€/kWh compared with operational costs per kWh of the baseline technology
- Yearly fixed costs (depreciation + overheads) per kWh of thermal energy supplied at each spot compared with fixed costs per kWh of the baseline technology*;*
- Yearly total costs per kWh of thermal energy supplied at each spot compared with total costs per kWh of the baseline technology
- Total cost (operating costs and yearly depreciation rates) per saved ton of CO_2e at each spot- *€/ton* CO_2e.

Social KPIs

- Number of working hours used for running and maintaining the system at each spot;
- Number and type of possible complaints (e.g. smells during maintenance or in case of system failure) by students, employees and citizens living in the neighbourhood at each spot;
- Internal floor area served by the new system at each spot- m^2;
- Number of end-users benefitting of the new system at each spot.

ID	KPI	Unit of Measurement	Formula	Comments
CO1T1	Energy efficiency at each spot	-	$$\frac{\sum_{year}\sum_{i} Q_{hp_i} + \sum_{year}\sum_{k} Q_{boiler_k}}{f_{el}\cdot\sum_{year}\left(\sum_{i} C_{hp,i} + C_{wp} + \sum_{i} C_{st,i} + \sum_{k} C_{b,k} + C_{aux} + \sum_{j} C_{dist,j}\right) + f_{th}\cdot\sum_{year}\sum_{k} Q_{boiler,k}}$$	The denominator of the ratio represents the primary energy consumption in the new system at each spot. This indicator will be estimated by taking into account specific conversion factor of electric and thermal energy into primary energy (respectively, f_{el} and f_{th}). $Q_{boiler,k}$ is the thermal energy provided by the peak gas boilers (calculated on the basis of the monitored gas consumptions, $G_{gas\ boiler,\ k}$)
CO1T2	Seasonal COP for each heat pump system	-	$$\frac{\sum_{season} Q_{hp,i}}{\sum_{season}\left(C_{hp,i} + C_{aux}\right)}$$	-
CO1T3	Variation of primary energy in comparison with the baseline situation at each spot	-	$$\frac{Pe - Pe_{baseline}}{Pe_{baseline}}$$	Pe and $Pe_{baseline}$ are respectively the primary energy consumption in the current and baseline situation
CO1T4	Energy efficiency variation in comparison with the baseline situation at each spot	-	$$\frac{Co1T1 - Eff_{baseline}}{Eff_{baseline}}$$	$Eff_{baseline}$ is the energy efficiency in the baseline situation (ratio between produced thermal energy and primary energy consumption)

Table 14- Technical KPIs (CO1)

ID	KPI	Unit of Measurement	Formula	Comments
CO1En1	Variation of pollutant emissions with reference to the baseline situation at each spot	*Kg/year of saved TSP, NOx, CO,* CO_2	$\sum_{year}\left(G_{gas,baseline}-\sum_k G_{gas_k}\right)\cdot E_{gas-boiler}-\sum_{year} C_{tot}\cdot E_{el\ grid}$	The calculation will take into account the specific emission factors ($E_{el\ grid}$) for each pollutant based on average electricity grid in Germany in order to estimate emissions connected to the total electric energy consumption of the entire heat pump system (C_{tot}); at the same time emission factors associated to gas consumption in condensing gas boilers (E_{boiler}) will be taken into account (both in the new and in the baseline situation) in order to estimate the variation of emission for each considered pollutant in comparison with the baseline situation.
CO1En2	Yearly GHG savings at each spot	*Kg/year of saved* CO_2e	-	GHG emissions will be calculated by applying specific conversion factors in oder to convert greenhouse gas emission into CO_2 equivalent

Table 15- Environmental KPIs (CO1)

ID	KPI	Unit of Measurement
CO1Ec1	Yearly operational cost per kWh of thermal energy at each spot compared with operational costs per kWh of the baseline technology	*€/kWht*
CO1Ec2	Yearly fixed costs (depreciation + overhead) per kWh of thermal energy supplied at each spot compared with fixed costs per kWh of the baseline technology;	*€/kWht*
CO1Ec3	Yearly total costs per kWh of thermal energy supplied at each spot compared with total costs per kWh of the baseline technology	*€/kWht*
CO1Ec4	Total cost (operating costs and yearly depreciation rates) per saved ton of CO2e at each spot-	*€/ton* CO_2e

Table 16- Economic KPIs (CO1)

ID	KPI	Unit of Measurement
CO1S1	Number of working hours used for running and maintaining the system at each spot	*hours/year*
CO1S2	Number and type of possible complaints (e.g. smells during maintenance or in case of system failure) by students, employees and citizens living in the neighbourhood at each spot	-
CO1S3	Internal floor area served by the new system at each spot	m^2
CO1S4	Number of end-users benefitting of the new system at each spot	

Table 17- Social KPIs (CO1)

3.6 London demonstrator (LO1)

3.6.1 Objective of the demonstrator and baseline situation

The LO1 project developed by UK Power Networks differs from the other projects since it is specifically oriented to improve security of supply of electric energy at local level instead of improving energy efficiency.

The objective of this demonstrator is to implement a demand-response system (DR) to alleviate network's constraints and faults. 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. If DR can be used to reduce the demand on the substation, reducing the loading, the number and magnitude of these faults may be reduced or avoided. Times of elevated loading are referred to as a 'constraint'. When normal network running arrangements need to be reconfigured due to, for example, a damaged cable or blown fuse, this is referred to as a 'fault.' In this case the surrounding substations will need to meet any shortfall in electric energy distribution, elevating their load levels which can then result in them being constrained.

The load on the substation can be reduced thanks to the smart management of an existing district-scale co-generation system (which also feeds a DH system), that would be used also in case of network failures or excessive loading at a local substation.

In particular, in case the district demand of electric energy exceeds the maximum power that can be provided by the substation's transformers (due to exceptional demand or in the case of maintenance or equipment failure), the extra energy is provided by the cogenerator with no discomforts for users: in these situations, the worst case scenario would result in blackouts.

The possibility of using a cogenerator out of its normal use as a backup power generator implies varying its production profiles during periods where it operates at partial load, wasting some heat or accumulating it into its thermal buffer, and using it also – in case of need – during periods out of its use (i.e. in summer) venting the co-generated heat.

UK Power Networks will be working with Islington Council who owns the Combined Heat and Power unit (CHP) at Bunhill Energy Centre (BEC) to contract DR services as part of the Celsius project. The aim of this exercise is to learn how best to incorporate CHP-generated electric energy at times of network need.

The electric energy produced by the CHP plant during such operation is likely to often cause larger emissions than the power plants that commonly feed the grid. Nevertheless, the improved short term security of supply, service quality and grid stability are of upmost importance in smart energy systems, since LO1 project uses distributed energy as a tool to improve stability in a time, today, where distributed production is normally seen by grid operators as a complication to grid stability.

The project does not only take into account the physical features of these problems but also their economic consequences. Moreover, it is foreseen in the project both to use the system for facing real situations of faults, excessive loading and the associated shortages in supply and to simulate these situations, in order to better understand and tune the optimal demand-response mechanisms and the related business models.

Concerning the identification of the baseline situation, it makes sense to consider as LO1 baseline systems both a normal power station (with the average features of the British electric grid, eventually assessing the typical profiles during peak hours and low demand hours) and a typical diesel backup system: the first one can provide the typical difference between the LO1 proposal

and an alternative solution considering an empowerment of the local substation; the second one provides the baseline typical situation where security of supply is an indispensable solution (e.g. a hospital).
A simplified layout of the implementation solution in the demonstrator LO1 is reported in the figure below.

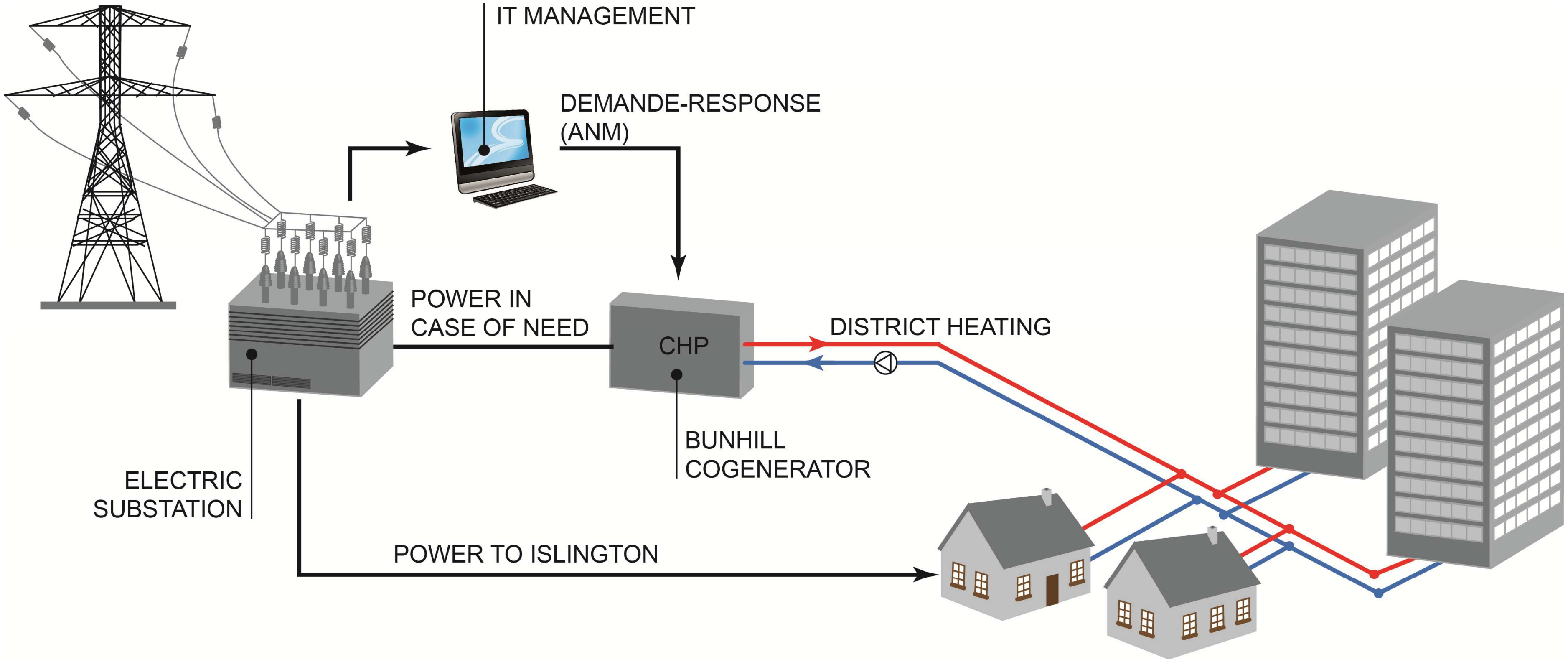

Figure 7: *LO1 simplified layout*

3.6.2 List of specific KPIs

Technical KPIs

In the following list both security of supply and energetic aspects are included.

- Number of power interruptions avoided in a year;
- Number of power quality issues avoided in a year;
- Number of power interruptions not avoided in a year;
- Number of power quality issues not avoided in a year;
- Number of fines avoided in a year;
- Yearly amount of natural gas used by the cogenerator for assisting the substation- Nm^3*/year;*
- Yearly amount of electric energy produced by the cogenerator for assisting the substation- *MWhe/year;*
- Additional thermal losses due to the shift between production and consumption during the heating season- *MWht/year.*

Environmental KPIs

- Variation of emissions with reference to baseline situation- *% of variation and kg/year of* PM_{10}, $PM_{2.5}$, *TSP*, NO_x, SO_x, *CO*, CO_2;
- Yearly GHG variation- *% of variation and kg/year of* CO_2e.

Economic KPIs

- Operation and maintenance costs of the cogenerator used in assistance of the substation paid by BEC, considering both the part sustained to ensure the system availability and that sustained for the actually used service- *€/year;*
- Extra-cost for gas consumption used in assistance of the substation paid by BEC- *€/year;*
- Total earnings for BEC due to the service given to UKPN- *€/year;*
- Total amount of fines avoided by UKPN thanks to the cogenerator assistance, divided per each typo of fault backed by the cogenerator, among those truly occurred and those simulated- *€/year per typology of faults;*
- Extra fee paid by UKPN to BEC per each type of fault backed by the cogenerator, among those truly occurred and those simulated- *€/year per typology of faults;*
- Extra cost sustained by BEC per each type of fault backed by the cogenerator, among those truly occurred and those simulated- *€/year per typology of faults.*

Social KPIs

- Number of residents/users benefitting of the new project;
- Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation;
- Working hours per year for operation and maintenance of the new system- *hours/year*.

ID	KPIs	Unit of Measurement	Formula	Comments
LO1T1	Number of power interruptions avoided in a year	-	-	-
LO1T2	Number of power quality issues avoided in a year			
LO1T3	Number of power interruptions not avoided in a year		-	
LO1T4	Number of power quality issues not avoided in a year			
LO1T5	Number of fines avoided in a year			
LO1T6	Yearly amount of natural gas used by the cogenerator for assisting the substation	*Nm^3/year*	$\sum_{year} G_{CHP}$	-
LO1T7	Yearly amount of electric energy produced by the cogenerator for assisting the substation	*MWhe/year*	$\sum_{year} P_{CHP}$	-
LO1T8	Additional thermal losses due to the shift between production and consumption during the heating season	*MWht/year*	$\sum_{year} \left(Q_{CHP} - Q_{DH}\right)$	-

Table 18- Technical KPIs (LO1)

ID	KPIs	Unit of Measurement	Formula	Comments
LO1En1	Variation of emissions with reference to baseline situation	*Kg/year of saved TSP, NOx, CO, CO_2*	$\sum_{year} P_{CHP} \cdot \left(E_{elCHP} - E_{el,baseline}\right)$	Emissions will be calculated by taking into account the specific emission factors ($E_{el\ CHP}$) for each pollutant relative to the CHP (based on periodical controls if available, from specific nameplates of the equipments and/or available data provided by the demo responsible partners); baseline situation will be estimated by taking into account both specific emission factors of the electric grid (baseline 1) and of a typical diesel back-up solution (baseline 2)
LO1En2	Yearly GHG savings	*Kg/year of saved CO_2e*		GHG emission will be calculated by applying specific conversion factors to greenhouse gas emissions for their conversion into kg CO2e

Table 19- Environmental KPIs (LO1)

ID	KPIs	Unit of Measurement	Formula	Comments
LO1Ec1	Cost for O&M of the cogenerator used in assistance of the substation paid by BEC, divided between the part sustained to ensure the system availability and that sustained for the actually used service	€/year	$\sum_{year} M_{CHP}$	-
LO1Ec2	Extra-cost for gas consumption used in assistance of the substation paid by BEC	€/year	$LO1T6 \cdot T_{gas,CHPmanager}$	-
LO1Ec3	Total earnings for BEC due to the service given to UKPN	€/year	$\sum_{year} F_{CHP}$	-
LO1Ec4	Total amount of fines avoided by UKPN thanks to the cogenerator assistance, divided per each typo of fault backed by the cogenerator, among those truly occurred and those simulated	€/year per typology of faults		This indicator is derived by the number of fines avoided in a year
LO1Ec5	Extra fee paid by UKPN to BEC per each type of fault backed by the cogenerator, among those truly occurred and those simulated	€/year per typology of faults		-
LO1Ec6	Extra cost sustained by BEC per each type of fault backed by the cogenerator, among those truly occurred and those simulated	€/year per typology of faults		-

Table 20- Economic KPIs (LO1)

ID	KPIs	Unit of Measurement
LO1S1	Number of residents/users benefitting of the new project	-
LO1S2	Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation	-
LO1S3	Working hours per year for O&M of the new system-	*hours/year*

Table 21-Social KPIs (LO1)

3.7 London demonstrators (LO2+LO3)

3.7.1 Objective of the demonstrator and baseline situation

London Borough of Islington Council recently completed the first phase of Bunhill Heat and Power, a 1km heat network served by a 2MWe gas CHP engine. The second phase which will be developed in the framework of the Celsius project (LO2 & 3) intends to recover waste heat from a large electric energy substation and a London Underground mid-tunnel ventilation shaft using heat pump technology. It also aims to provide heating to an additional 620 council owned homes and around 1,000 new build homes, 5,000m^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.

Within this district heating project, the Celsius demonstrators include the increase of thermal power supply of the district heating (LO2) and the increase of the number of buildings served by the district heating (LO3).

The first waste heat source is a large electric substation where 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 heat is currently lost to the environment. Separate from the substation, a nearby London Underground mid-tunnel ventilation shaft ventilates the tube through the use of mechanical ventilation exhausting warm air into the environment. In both cases, heat will be captured using heat exchangers and heat pump systems. The heat pump COP's achievable are estimated to be approximately 3 for the ventilation shaft to approximately 5.5 for the electrical transformer at peak operating temperature. The peak thermal output available (approximately 1.16 MW) is expected to meet the base load for the connected properties.

Islington Council plans to incorporate a thermal store close to the electrical substation heat pump to even out demand if necessary. However, a better use of the existing 115 m^3 thermal storage will be implemented through increased temperature differential across the store.

One more general baseline situation (baseline 1) for LO2-3 project will be referred to the common mix of heating systems used in London, consisting of natural gas fired boilers, oil fired boilers, electric heaters and electric heat pumps. The reference and typical features of these systems will be a census of heating systems at city level or, better, at district level or, even better, a study done on the new loads to be connected to the district heating system during LO3 expansion.

A more specific baseline situation (baseline 2) will also be taken into account by considering the alternative heating system for each of the connections – i.e. for existing buildings the current heating system and for new buildings the alternative heating system that would be required to meet planning requirements and Building Regulations.

A simplified layout both of LO2 and LO3 projects is reported in the figures below (temperatures reported in the figure 8 may require to be amended in accordance to actual implementation of the demonstrator).

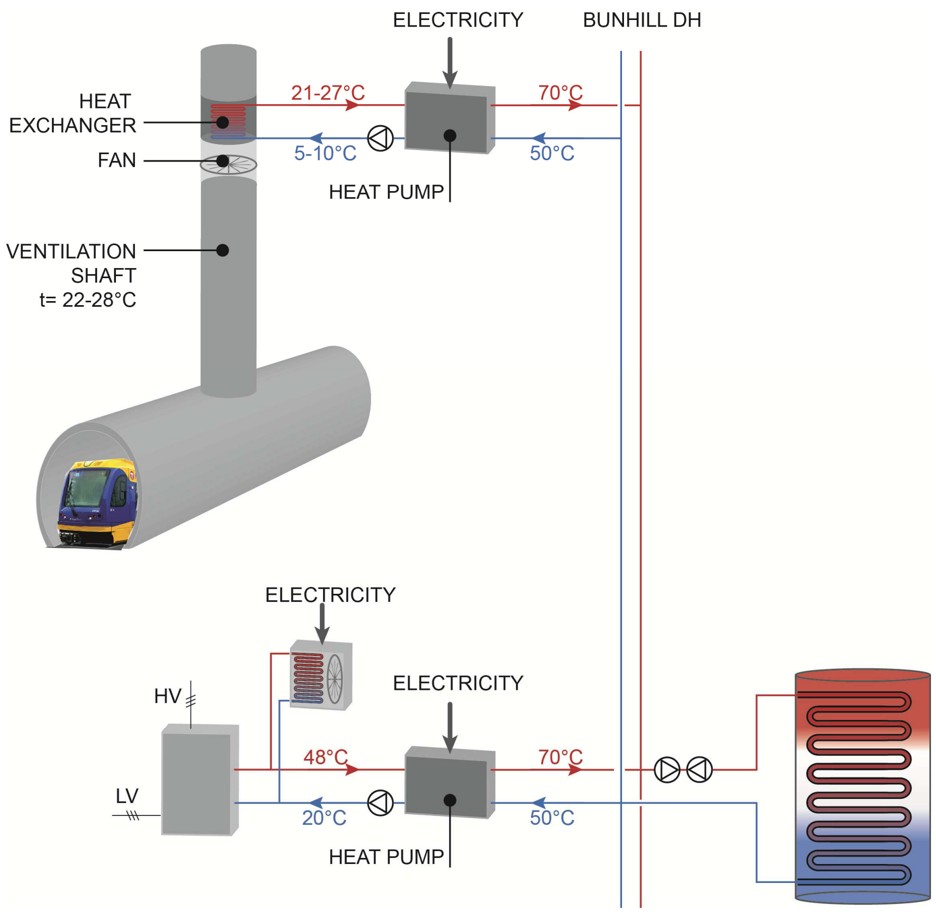

Figure 8: *LO2 simplified layout*

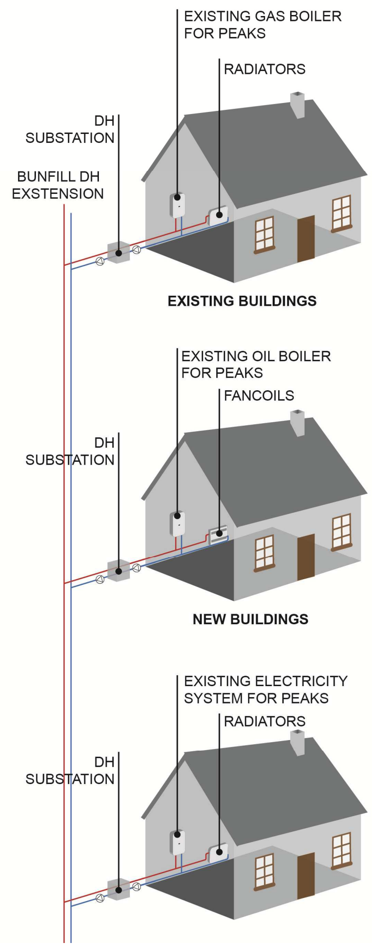

Figure 9: *LO3 simplified layout*

3.7.2 List of specific KPIs

Technical KPIs

- Yearly amount of electric energy used by the installed heat pump system at ventilation shaft (A), transformer (B) and thermal storage (C)- *MWhe/year;*
- Seasonal COP of the heating pump system at ventilation shaft and transformer;
- Yearly amount of thermal energy recovered/provided by ventilation shaft (A), transformer (B) and thermal storage (C) - *MWht/year;*
- Thermal energy delivered to the buildings connected to the district heating system in the expansion of the network- *MWht/year;*

Environmental KPIs

- Variation of emissions with reference to baseline situation- *kg/year of* PM_{10}, $PM_{2.5}$, *TSP*, NO_x, SO_x, *CO*, CO_2 *and % of variation;*
- Yearly GHG variation- *% of variation and kg/year of* CO_2e.

Economic KPIs

- Yearly cost for electric energy consumption at ventilation shaft (A), transformer (B) and thermal storage(C)- *€/year;*
- Maintenance costs at ventilation shaft (A), transformer (B) and thermal storage (C)- *€/year;*
- Yearly savings for the end-user-*€/year per end-user*.

Social KPIs

- Additional buildings connected to the district heating system;
- Internal surface served by the new system- m^2;
- Number of residents benefitting of the new system;
- Number of workplaces benefitting of the new system.

ID	KPIs	Unit of Measurement	Formula
LO2-3T1	Yearly amount of electric energy used by the installed heat pump system at ventilation shaft (*A*), transformer (*B*) and thermal storage (*C*)	*MWhe/year*	$\sum_{year} C_{hp,A}$ $\sum_{year} C_{hp,B}$ $\sum_{year} C_{C}$
LO2-3T2	Seasonal COP of the heating pump systems at ventilation shaft (*A*) and transformer (*B*)	-	$\frac{\sum_{year} Q_{hp,A}}{\sum_{year} C_{hp,A}}$ $\frac{\sum_{year} Q_{hp,B}}{\sum_{year} C_{hp,B}}$
LO2-3T3	Yearly amount of thermal energy recovered/provided by A, B and C	*MWht/year*	$\sum_{year} Q_{hp,A}$ $\sum_{year} Q_{hp,B}$ $\sum_{year} Q_{C\ out}$
LO2-3T4	Thermal energy delivered to the buildings connected to the district heating system in the expansion of the network	*MWht/year*	$\sum_{year} \sum_{i} Q_{build_i}$

Table 22- Technical KPIs (LO2-3)

celsius smart cities

ID	KPIs	Unit of Measurement	Formula	Comments
LO2-3En1	Variation of emissions with reference to baseline situation	*Kg/year of saved TSP, NOx, CO,* CO_2	$LO2,3T\,4\sum_{fuel,i}\frac{E_i}{\eta_i}\cdot w_i-\sum_{year}C_{tot}\cdot E_{el\ grid}$	The calculation will take into account the specific emission factors ($E_{el\ grid}$) for each pollutant based on average electricity grid in the United Kingdom in order to estimate emissions connected to the total electric energy consumption of the new entire system A+B+C (C_{tot}); at the same time emission factors associated to the consumption of each typology of fuel in the different heating systems (common mix used in London) will be taken into account (E_i). This factor must be corrected according to the specific efficiency, ŋi, of each equipment using the fuel *i* and the relative weight *wi* of each equipment on the identified mix distribution which is representative of the baseline situation
LO2-3En2	Yearly GHG savings	*Kg/year of saved* CO_2e	-	GHG emission will be calculated by applying specific conversion factors in order to convert greenhouse gas emissions into kg of CO_2 equivalent

Table 23- Environmental KPIs (LO2-3)

ID	KPIs	Unit of Measurement	Formula	Comments
LO2-3Ec1	Yearly cost for electric energy consumption at ventilation shaft (A), transformer (B) and thermal storage (C)	*€/year*	$LO2{,}3T1 \cdot T_{el,DHM}$	-
LO2-3Ec2	Maintenance costs at ventilation shaft (A), transformer (B) and thermal storage (C)	*€/year*	$\sum_{year} M_A$ $\sum_{year} M_B$ $\sum_{year} M_C$	-
LO2-3Ec3	Yearly savings for the end-user	*€/year end-user*	$\frac{LO2{,}3T4 \cdot T_{th,end-user} - Q_{baseline} T_{baseline}}{N_{end-user}}$	$T_{baseline}$ is calculated from the cost of fuels and electric energy used for space heating in the baseline situation in accordance to the mix of sources used for heating purposes. $Q_{baseline}$ is the thermal energy provided to buildings in the baseline situation.

Table 24- Economic KPIs (LO2-3)

ID	KPIs	Unit of Measurement
LO2-3S1	Additional buildings connected to the district heating system	-
LO2-3S2	Internal surface served by the new system	m^2
LO2-3S3	Number of residents benefitting of the new system;	-
LO2-3S4	Number of workplaces benefitting of the new system	-

Table 25- Social KPIs (LO2-3

3.8 Rotterdam demonstrator: RO1

3.8.1 Objective of the demonstrator and baseline situation

The district heating system of Rotterdam was established in 1948 and it is currently sourced by two E.ON-owned CHP's and several local gas-fired peak plants. The district heating system is mainly situated in the city centre and in 2003 an investigation into a major expansion of the district heating system was started.

One of the major steps taken by Warmtebedrijf Rotterdam (Heating Transport Company) has consisted in the establishment of a network 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. Warmtebedrijf Rotterdam has realised a 26 km transport infrastructure with a thermal capacity of 105 MW.

RO1 demonstrator (The Heat Hub) focuses on increasing the effectiveness of the waste heat transportation network of Warmtebedrijf Rotterdam with buffering, heat balancing, smart ICT and forecasting. It allows for an increase in total heat delivery of the waste heat network without any additional investments in a new transport infrastructure or by means of additional heat sources.

The heat hub will be constituted of three different parts:

- A distribution station for the connection of the existing district heating systems to the south and north of Rotterdam;
- A well-insulated buffering tank with a buffering capacity of 185MWh and a discharge capacity of 30MWth. By placing the tank in the middle of the distribution network, instead of at the traditional location in the vicinity of the production facilities, Warmtebedrijf Rotterdam increases the effectiveness of the buffering capacity, because the buffered heat is closer to the end-consumer. There is also a positive effect on the local air quality because there are less gas-fired boilers needed for peak load;
- A smart ICT-system for improving forecasting and heat balancing. This ICT system is a crucial element in further optimization of heat sources, buffers, new connections and pumping stations in the waste heat transportation infrastructure of Warmtebedrijf Rotterdam and the entire district heating system.

Therefore, the use of the heat hub itself will result in additional substitution of heat produced by fossil fuels by that produced from recovered industrial waste heat, reducing the correspondent emission levels. The smart ICT system will contribute in this sense by optimized matching of heat capacity and the heat demand in the city of Rotterdam through the use of the heat buffer.

The baseline situation will be referred to the common mix of heating systems used in Rotterdam, consisting of natural gas fired boilers, oil fired boilers, electric heaters and electric heat pumps. The reference and typical features of these systems might be a census of heating systems at city level or, better, at district level or, even better, a study done on the new loads to be connected to the district heating system

A simplified scheme of the Heat Hub is represented in the figure below

celsius smart cities

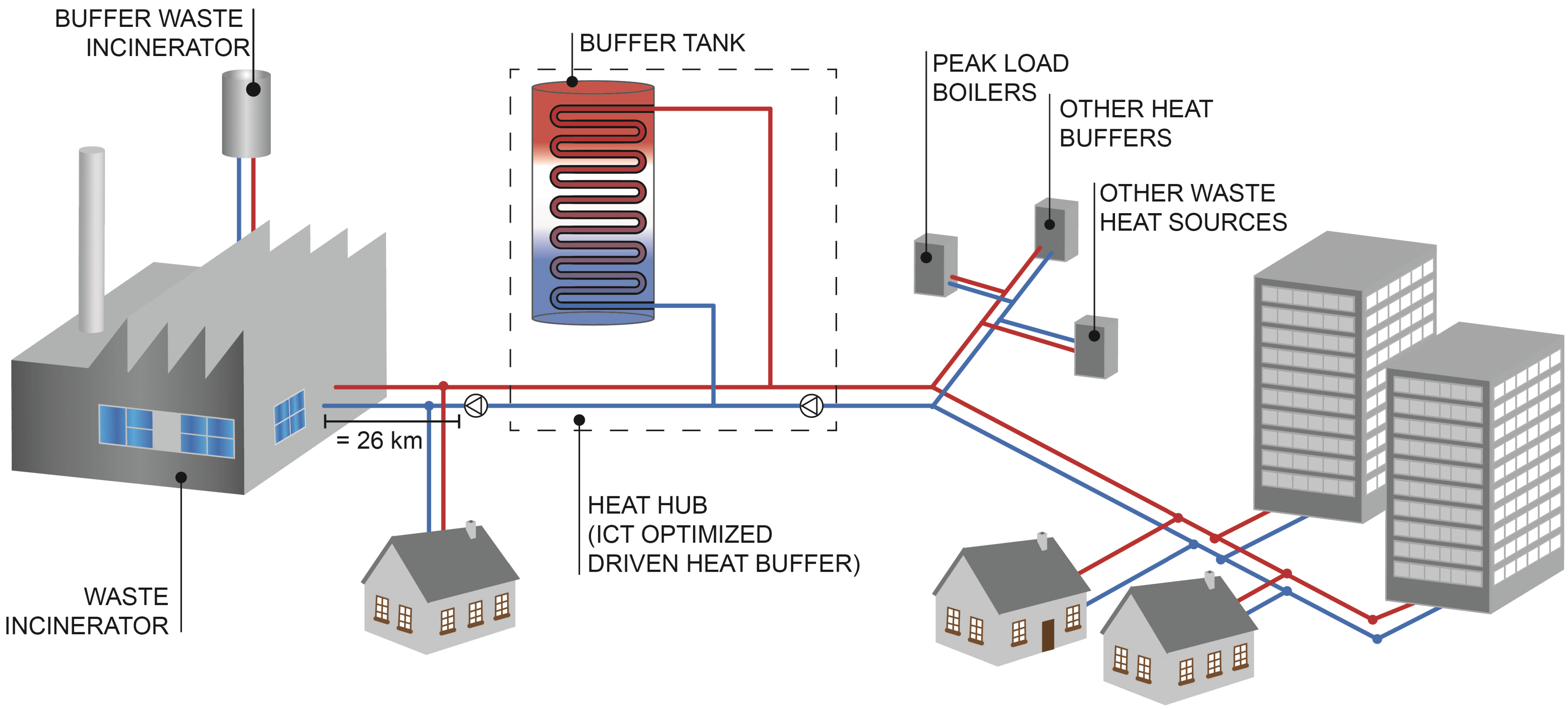

Figure 10: *RO1 simplified layout*

3.8.2 List of specific KPIs

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.

Technical KPIs

- Yearly amount of waste energy recovered by the heat hub- *MWht/year* ;
- Yearly electric energy consumption of the buffer pump versus the yearly thermal energy loading and unloading buffer tank- *MWhe/year and MWh/year*.
- Maximizing capacity of heat exchanger by utilizing the buffer- % per year

Environmental KPIs

- Yearly savings of CO_2- metric ton/year
- Yearly savings of NO_x- metric ton/year

ID	KPIs	Unit of Measurement	Formula
RO1T1	Yearly amount of waste energy recovered by the heat hub	*MWht/year*	$\sum_{year} Q_{in}$
RO1T2	Yearly electric energy consumption of the buffer pump versus the yearly thermal energy loading and unloading buffer tank	MWhe/year and MWht/year	$\sum_{year} \frac{C_{pump}}{Q_{buffer}}$
RO1T2	Maximizing capacity of heat exchanger by utilizing the buffer	% per year	

Table 26- Technical KPIs (RO1)

ID	KPIs	Unit of Measurement
RO1En1	Yearly savings of CO_2	*ton/year*
RO1En2	Yearly savings of NOx	*ton/year*

Table 27- Environmental KPIs (RO1)

3.9 Rotterdam demonstrator: RO2

3.9.1 Objective of the demonstrator and baseline situation

RO2 Industrial Ecology consists of the integration of existing industrial sites with the heat hub developed by Warmtebedrijf Rotterdam (RO1). The two industrial sites involved in RO2 demonstrator are Meneba, a grain processing plant, and RWZI Dokhaven, a wastewater treatment plant. Both Meneba and the wastewater treatment plant are located near the heat hub of Warmtebedrijf Rotterdam.

Currently the total heat demand of Meneba is supplied by a steam boiler, including the heat demand of activities with lower temperature requirements. The aim of the RO2 demonstrator is to use district heating for lower temperature requirements instead of steam. The total demand for waste heat is between 20,000 GJ and 40,000 GJ per year.

At RWZI Dokhaven plant, the sludge of wastewater is converted by anaerobic fermentation into biogas which is then fed as a fuel to a CHP for the coproduction of electric energy and thermal energy. Heat produced largely exceeds the needs of the plant and is mostly wasted. The existing CHP is at the end of its life cycle and needs to be substituted.

The objective of the demonstrator is to feed the heat from the new CHP into the waste heat transportation infrastructure of Warmtebedrijf Rotterdam, by developing a connection between the CHP and the waste heat transport infrastructure of Warmtebedrijf Rotterdam to the heat hub. The heat hub acts as a distribution station to the southern and northern parts of Rotterdam.

For feasible integration of existing industrial sources with the waste heat transportation structure, new business models need to be developed.

For this specific case, the baseline situation will be referred to the situation prior to the implementation of the technical solution, where thermal energy from biogas cogeneration is only partially exploited for heating the anaerobic digester at RWZI Dokhaven plant and heat at Meneba grain processing plant is provided by conventional steam boilers also for low temperature requirements.

A simplified layout of the process is represented in the figure below:

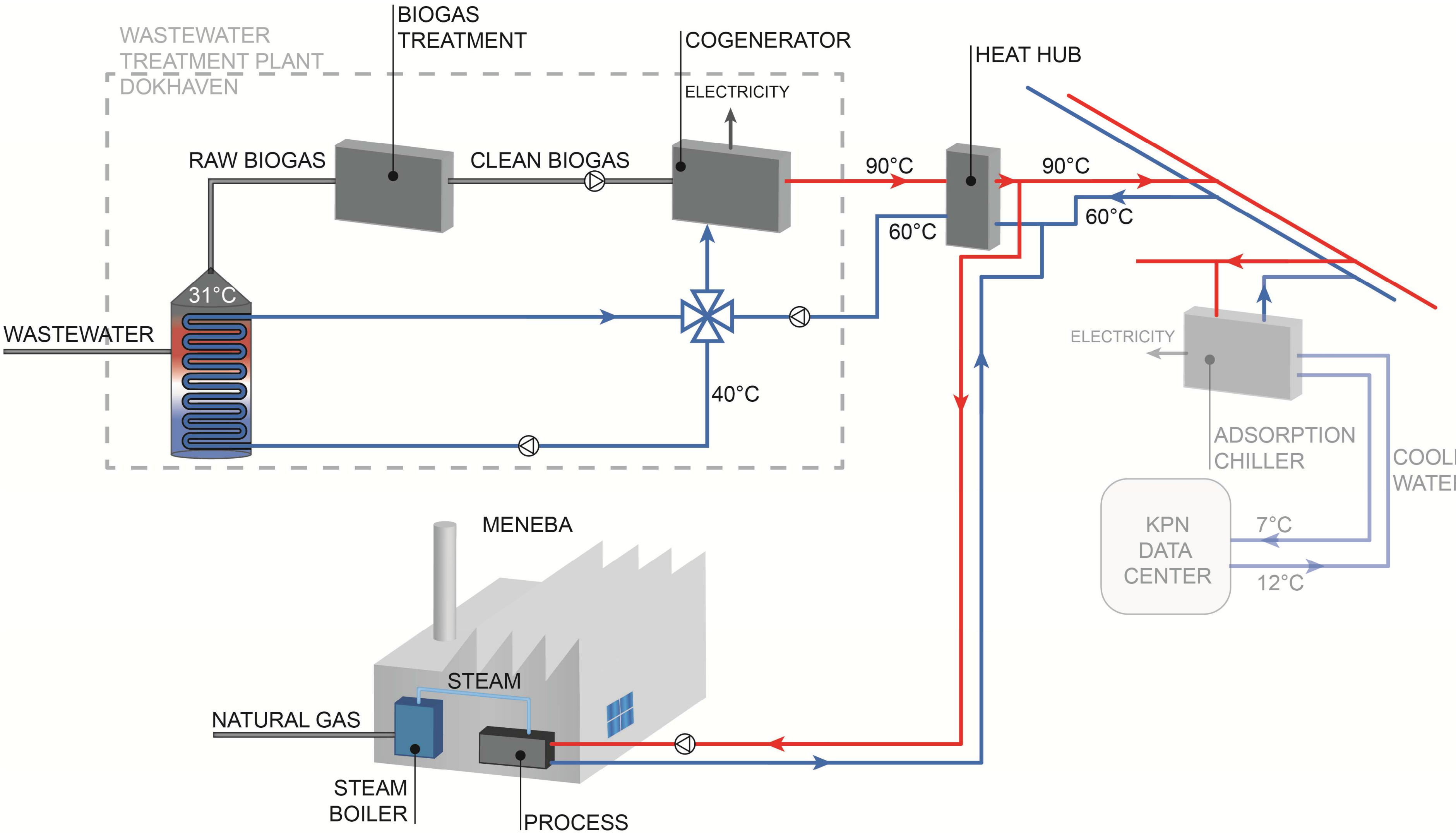

Figure 11: *RO2 simplified layout*

3.9.2 *List of specific KPIs*

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.

Wastewater treatment plant

Technical KPIs

- Rate of waste energy recovery and comparison with the baseline situation- *MWh/year;*

Environmental KPIs

- Yearly savings of CO_2- metric ton/year
- Yearly savings of NO_x- metric ton/year

Social KPIs

- Estimation of the number of services and persons benefitting of the intervention;
- Estimation of new job opportunities created thanks to the implementation of the demonstrator.

Meneba

Technical KPIs

- Rate of waste energy recovery and comparison with the baseline situation- *MWh/year;*

Environmental KPIs

- Yearly savings of CO_2- metric ton/year
- Yearly savings of NO_x- metric ton/year

Social KPIs

- Estimation of number of services and persons benefitting of the intervention (if measurable);
- Estimation of new job opportunities created thanks to the implementation of the demonstrator (if measurable).

ID	KPIs	Unit of Measurement	Formula	Comments
RO2T1	Rate of waste energy recovery and comparison with the baseline situation at WWTP	*MWht/year*	$\sum_{year} Q_{CHP,HH}(Q_{CHP,CHP})$	
RO2T2	Rate of waste energy recovery and comparison with the baseline situation at Meneba	*MWht/year*	$\sum_{year} Q_{Men,HH}(Q_{Men,Men})$	

Table 28- Technical KPIs (RO2)

ID	KPIs	Unit of Measurement
RO2En1	Yearly savings of CO_2 at WWTP	*ton/year*
RO2En2	Yearly savings of NOx at WWTP	*ton/year*
RO2En3	Yearly savings of CO_2 at Meneba	*ton/year*
RO2En4	Yearly savings of NOx at Meneba	*ton/year*

Table 29- Environmental KPIs (RO1)

4. Specific key-performance indicators: 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.
The methodology followed for setting-up the key-performance indicators 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 specific indicators which are really meaningful for the purposes of the project in terms of potential of replicability of the technology. Where not explicitly mentioned, general KPIs (chapter 5) will be sufficient for describing the performance of each demonstrator.
Moreover, considering that in most cases the existing demonstrators are in operation since many years and thus they can be considered as steady-state plants, the calculation of the specific and generic KPIs will be performed once during the project duration covering an entire year as reference period.
In the sub-paragraphs below, the analysis of each existing demonstrator which is part of the Celsius project is reported by including a short description of the implemented technology and of the correspondent baseline situation, the list of relevant specific KPIs and a summary table reporting, when necessary, the respective formulas for calculation.

4.1 Gothenburg Demonstrator (9GOe)

4.1.1 Objective of the demonstrator and baseline situation

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.
The original use of coal boiler is assumed as the baseline situation for estimating the performance of the demonstrator.

4.1.2 List of specific KPIs

Technical KPIs

- Yearly thermal energy production- *MWht/year;*
- Change in yearly thermal energy production in comparison with the baseline situation- *MWht and % of variation;*
- Yearly electric energy production- *MWhe/year;*
- Share of thermal energy provided by this demonstrator to the Gothenburg district heating mix - *%;*
- District heating supply temperature (yearly average, summer average and winter average)- *°C;*
- District heating return temperature (yearly average, summer average and winter average) -*°C*
- Power-to-heat ratio (ratio between electric and thermal energy production)

For the economic, environmental and social aspects, the general KPIs as defined in the chapter 5 will be sufficient for the evaluation of the performance of this demonstrator.

ID	KPI	Unit of Measurement	Formula
9GOeT1	Yearly thermal energy production	*MWht/year*	$\sum_{year} Q_{CHP}$
9GOeT2	Change in yearly thermal energy production in comparison with the baseline situation	*%*	$\frac{\sum_{year} (Q_{CHP} - Q_{baseline})}{\sum_{year} Q_{baseline}}$
9GOeT3	Yearly electric energy production	*MWhe/year*	$\sum_{year} P_{CHP}$
9GOeT4	Share of thermal energy provided by this demonstrator to the Gothenburg district heating mix	*%*	$\frac{\sum_{year} Q_{CHP}}{\sum_{year} Q_{DH}}$
9GOeT5	District heating supply temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{s,DH}}{period}$
9GOeT6	District heating return temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{r,DH}}{period}$
9GOeT7	Power-to-heat ratio (ratio between electric and thermal energy production)	*dimensionless*	$\frac{9GOeT3}{9GOeT1}$

Table 30- Technical KPIs (9GOe)

4.2 Gothenburg Demonstrator (29GOe)

4.2.1 Objective of the demonstrator and baseline situation

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.

The same buildings with standard energy contracts before signing the Climate Agreement will be considered as the baseline situation.

4.2.2 List of specific KPIs

<u>Technical KPIs</u>

- Yearly thermal energy consumption in buildings with “climate agreement” - *MWht/year-;*
- Yearly thermal energy consumption per square meter of heated area in buildings with “climate agreement” - *MWht/m^{2}year;*
- Yearly reduction of thermal energy consumption in comparison with baseline situation - *MWht/year and %.*

<u>Economic KPIs</u>

- Yearly savings for the end-user - *€/year.*

<u>Social KPIs</u>

- Average indoor air temperature-*°C;*
- Standard deviation of indoor air temperature in a building with climate agreement -*°C;*
- Share of customers appreciating the situation with the “climate agreement”- *%.*

ID	KPI	Unit of Measurement	Formula	Comments
29GOeT1	Yearly thermal energy consumption in buildings with “climate agreement”	*MWht/year*	$\sum_{year} Q_{agreem}$	-
29GOeT2	Yearly thermal energy consumption per square meter of heated area in buildings with “climate agreement”	*kWht/m²year*	$\frac{\sum_{year} Q_{agreem}}{A_{temp}}$	-
29GOeT3	Yearly reduction in thermal energy consumption in comparison with baseline situation	*MWh/year and % with reference to baseline situation*	$\frac{\sum_{year} (Q_{agreem} - Q_{baseline})}{\sum_{year} Q_{baseline}}$	-

Table 31- Technical KPIs (29GOe)

ID	KPI	Unit of Measurement	Formula	Comments
29GOeEc1	Yearly savings for the end-user	*€/year*	$T_{th,end-user,baseline} \sum_{year} Q_{baseline} - T_{th,end-user} \sum_{yrear} Q_{agreem}$	-

Table 32- Economic KPIs (29GOe)

ID	KPI	Unit of Measurement	Comments
29GOeS1	Average indoor air temperature, (yearly average, summer average, winter average)	*°C*	-
29GOeS2	Standard deviation of indoor air temperature in a building with climate agreement	*°C*	
29GOeS3	Share of customers appreciating the situation with the “climate agreement”	-	

Table 33- Social KPIs (29GOe)

4.3 Gothenburg Demonstrator (19GOe)

4.3.1 Objective of the demonstrator and baseline situation

The aim of this demonstrator, “Absorption cooling”, is to produce energy 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 of cooling energy is produced yearly, corresponding to 37 % of the total district cooling production in Gothenburg.

Electric chillers used for cooling individual buildings are considered as the baseline situation of this specific case.

4.3.2 List of specific KPIs

Technical KPIs

- Share of district cooling produced from absorption chillers - %;
- Period of the year when absorption chillers are used in district cooling;
- Seasonal performance factor;
- Use of thermal energy from district heating (yearly average)- $MWht/MWht_{cold}$;
- Yearly electric energy consumption - $MWht/MWht_{cold}$;
- District cooling supply temperature (yearly average, summer average and winter average) -*°C;*
- District cooling return temperature (yearly average) -*°C;*
- District heating supply temperature (yearly average, summer average and winter average) -*°C;*
- District heating return temperature (yearly average, summer average and winter average) -*°C;*

Economic KPIs

- Pay-back time for energy company – *years;*
- Pay-back time for end-users – *years.*

Environmental KPIs

- Reduced consumption of refrigerants- *kg/year*.

ID	KPI	Unit of Measurement	Formula
19GOeT1	Share of district cooling produced by absorption chillers	*%*	$\frac{\sum_{year} Q_{C,DC}}{\sum_{year} Q_{DC}}$
19GOeT2	Period of the year when absorption chillers are used in district cooling	*Date-date*	
19GOeT3	Seasonal performance factor	-	$\frac{\sum_{season} Q_{C,DC}}{\sum_{season} C_{c}}$
19GOeT4	Use of thermal energy from district heating (yearly average)	$MWht_{cold}/MWht$	$\frac{\sum_{year} Q_{C,DC}}{\sum_{year} Q_{mix,DH}}$
19GOeT5	Yearly electric energy consumption	*MWhe/year*	$\sum_{year} C_{C} + \sum_{year} C_{DC} + \sum_{year} C_{DH}$
19GOeT6	District cooling supply temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{s,DC}}{period}$
19GOeT7	District cooling return temperature (yearly average)	*°C*	$\frac{\sum_{period} Te_{r,DC}}{period}$
19GOeT8	District heating supply temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{s,DH}}{period}$
19GOeT9	District heating return temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{r,DH}}{period}$

Table 34- Technical KPIs (19GOe)

ID	KPI	Unit of Measurement	Formula	Comments
19GOeEc1	Pay-back time for energy company	*years*		Based on investment costs for absorption chillers and district cooling network, operating costs, maintenance costs and revenues from sold energy
19GOeEc2	Pay-back time for end-user	*years*		Based on investment costs for the extra investment, operating costs and estimated economic savings

Table 35- Economic KPIs (19GOe)

ID	KPI	Unit of Measurement	Formula	Comments
19GOeEn1	Reduced consumption of refrigerants	*kg/year*		-

Table 36- Environmental KPIs (19GOe)

4.4 Gothenburg Demonstrator (11GOe)

4.4.1 Objective of the demonstrator and baseline situation

The aim of this demonstrator, "Cooling by river water", is to produce cooling energy for the district cooling network by means of using river water in heat exchangers used to cool water, i.e. free cooling. Total installed capacity is 15 MW and 43 GWh are produced yearly, corresponding to 35 % of the total district cooling production in Gothenburg.
Electric chillers used for cooling individual buildings are considered as the baseline situation of this specific case.

4.4.2 List of specific KPIs

<u>Technical KPIs</u>

- Share of district cooling produced as free cooling by river water - %;
- Period of the year when river water can be used directly in district cooling;
- Seasonal performance factor;
- Yearly electric energy consumption – *MWhe/year;*
- District cooling supply temperature (yearly average, summer average and winter average) -*°C;*
- District cooling return temperature (yearly average) -*°C;*
- Temperature of river water to heat exchanger (yearly average, summer average and winter average) -*°C;*
- Temperature of water from heat exchanger back to the river (yearly average) -*°C;*

<u>Economic KPIs</u>

- Pay-back time for energy company – *years;*
- Pay-back time for end-user – *years.*

<u>Environmental KPIs</u>

- Reduced consumption of refrigerants- *kg/year*.

ID	KPI	Unit of Measurement	Formula
11GOeT1	Share of district cooling produced as free cooling by river water	*%*	$\frac{\sum_{year} Q_{r,DC}}{\sum_{year} Q_{DC}}$
11GOeT2	Period of the year when river water can be used directly in district cooling	*Date-date*	
11GOeT3	Seasonal performance factor	-	$\frac{\sum_{season} Q_{r,DC}}{\sum_{season} C_{r,DC}}$
11GOeT4	Yearly consumption of electric energy	*MWhe/year*	$\sum_{year} C_{DC} + \sum_{year} C_{r,DC}$
11GOeT5	District cooling supply temperature (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{s,DC}}{period}$
11GOeT6	District cooling return temperature (yearly average)	*°C*	$\frac{\sum_{period} Te_{r,DC}}{period}$
11GOeT7	Temperature of river water to heat exchanger (yearly average, summer average and winter average)	*°C*	$\frac{\sum_{period} Te_{s,river}}{period}$
11GOeT8	Temperature of water from heat exchanger back to the river (yearly average)	*°C*	$\frac{\sum_{period} Te_{r,river}}{period}$

Table 37- Technical KPIs (11GOe)

ID	KPI	Unit of Measurement	Comments
11GOeEc1	Pay-back time for energy company	Years	Based on investment costs for absorption chillers and district cooling network, operating costs, maintenance costs and revenues from sold energy
11GOe Ec2	Pay-back time for end-user	Years	Based on investment costs for the extra investment, operating costs and estimated economic savings

Table 38- Economic KPIs (11GOe)

ID	KPI	Unit of Measurement	Comments
11GOeEn1	Reduced consumption of refrigerants	kg/year	-

Table 39- Environmental KPIs (11GOe)

4.5 Gothenburg Demonstrator (20GOe)

4.5.1 Objective of the demonstrator and baseline situation

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 spaces and to produce domestic hot water, by reducing the quantity of heat that has to be produced at Göteborg Energi's production facilities.
The baseline situation will be referred to heat entirely supplied by the district heating system, i.e. the current production mix of the Gothenburg network will be compared to the solar heat system.

4.5.2 List of specific KPIs

<u>Technical KPIs</u>

- Specific heat output- *kWh/year m² collector area;*
- Temperature of delivered heat (yearly average)- *°C*
- Period of the year with significant heat production
- District heating supply temperature (yearly and winter/summer averages)- *°C*
- District heating return temperature (yearly and winter/summer averages)- *°C*

ID	KPI	Unit of Measurement	Formula	Comments
20GOeT1	Specific heat output	*kWh/year m² collector area*	$\frac{\sum_{year} Q_{SC}}{A_{coll}}$	
20GOeT2	Temperature of delivered heat (yearly average)	*°C*	$\frac{\sum_{period} T_{s,SC}}{period}$	
20GOeT3	Period of the year with significant heat production	*(months)*		This indicator will be defined based on production data
20GOeT4	District heating supply temperature, yearly and monthly averages	*°C*	$\frac{\sum_{period} Te_{s,DH}}{period}$	
20GOeT5	District heating return temperature, yearly and monthly averages	*°C*	$\frac{\sum_{period} Te_{r,DH}}{period}$	

Table 40- Technical KPIs (11GOe)

4.6 Gothenburg Demonstrator (8GOe)

4.6.1 Objective of the demonstrator and baseline situation

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 electricity. After the expansion in the turbine, the hot steam is cooled with district heating water and the transferred heat is delivered to the network. Flue gas from the combustion chamber is cooled down by providing additional heat to the district heating network.

The baseline situation will be referred to the case of no waste heat recovery, resulting in a consequent increase of the production at the Rya natural gas CHP facility.

4.6.2 List of specific KPIs

<u>Technical KPIs</u>

- Percentage of Gothenburg district heating produced by this demonstrator- *%*;
- Yearly net electric energy production- *MWhe/year*;
- Power-to-heat ratio (ratio between electric and thermal energy production);
- Yearly amount of incinerated waste (tons/year).

ID	**KPI**	**Unit of Measurement**	**Formula**
8GOeT1	Percentage of Gothenburg district heating produced by this demonstrator	*%*	$\frac{\sum_{year} Q_{inc}}{\sum_{year} Q_{DH,mix}}$
8GOeT2	Yearly net electric energy production	*MWh*	$\sum_{year} P_{inc} - \sum_{year} C_{inc}$
8GOeT3	Power-to-heat ratio (ratio between electric and thermal energy production)	*(dimensionless)*	$\frac{8GOeT2}{\sum_{year} Q_{inc}}$
8GOeT4	Amount of incinerated waste (tons)	*tons/year*	$\sum_{year} V_{waste}$

Table 41- Technical KPIs (8GOe)

4.7 Gothenburg Demonstrator (7GOe)

4.7.1 Objective of the demonstrator and baseline situation

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, heat 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.

The baseline situation will be referred to the case of no waste heat recovering, consequently increasing the production at the Rya natural gas CHP facility.

4.7.2 List of specific KPIs

- Waste heat temperature, yearly average -*°C;*
- Share of Gothenburg district heating produced by this demonstrator -%;
- District heating supply temperature - °*C*;
- District heating return temperature - *°C;*
- Electric energy consumptions needed for recovering waste heat - *MWhe/year*.

ID	KPI	Unit of Measurement	Formula	Comments
7GOeT1	Waste heat temperature, yearly average	*°C*	$Te_{waste,average}$	Values provided for each waste heat recovery site
7GOeT2	Share of Gothenburg district heating produced by this demonstrator	*%*	$\frac{\sum_{year} Q_{rec,DH}}{\sum_{year} Q_{mix,DH}}$	-
7GOeT3	District heating supply temperature (yearly , monthly and seasonal averages)	*°C*	$\frac{\sum_{period} Te_{s,DH}}{period}$	
7GOeT4	District heating return temperature (yearly, monthly and seasonal averages)	*°C*	$\frac{\sum_{period} Te_{r,DH}}{period}$	
7GOeT5	Electric energy consumption needed for recovering waste heat	*MWhe/year*	$\sum_{year} C_{tot}$	Values provided for each waste heat recovery site

Table 42- Technical KPIs (7GOe)

4.8 Gothenburg Demonstrator (36GOe)

4.8.1 Objective of the demonstrator and baseline situation

The demonstrator encompasses the entire district heating system and is intended to give an overview of an existing, mature district heating system in operation in Gothenburg. District heating has been developed in Gothenburg since 1953. The system has gradually expanded in terms of the 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.

4.8.2 List of specific KPIs

Technical KPIs

- Yearly delivered heat to customers per market sector - *MWht/year per market sector;*
- Yearly production mix - *% for each type of heat input;*
- District heating supply temperature - *°C*;
- District heating return temperature - *°C*
- Relative distribution losses - *%;*
- Yearly electric energy consumptions - *MWhe/year;*
- Linear heat density - *kWht/m;*

Social KPIs

- Number of users/customers per market sector;
- Market share in different sectors - *% of total number of customers*;
- Number of people employed directly and indirectly as a result of the district heating operation

ID	KPI	Unit of Measurement	Formula	Comments
36GOeT1	Yearly delivered heat to customers per market sector	*MWht/year*	$\sum_{year} Q_{sector,DH}$	Sectors: single-family homes, multi-dwelling buildings, commercial/public buildings, industries, ground heat.
36GOeT2	Yearly production mix	*% for each facility*	$\sum_{year} Q_{f,DH}$	Calculated for each facility (*f*)
36GOeT3	District heating supply temperature (yearly and winter/summer averages)	*°C*	$\frac{\sum_{period} Te_{s,DH}}{period}$	
36GOeT4	District heating return temperature (yearly and winter/summer averages)	*°C*	$\frac{\sum_{period} Te_{r,DH}}{period}$	
36GOeT5	Relative distribution losses	*%*	$\frac{\sum_{year}\sum_{facilities} Q_{f,DH} - \sum_{year}\sum_{sector} Q_{sector,DH}}{\sum_{year}\sum_{facilities} Q_{f,DH}}$	-
36GOeT6	Electric energy consumptions at each production facility	*MWhe/year*	$\sum_{year} C_{f,DH}$	Calculated for each facility (*f*)
36GOeT7	Linear heat density	*kWht/m*	$\frac{36GOeT1}{L_{pipe}}$	-

Table 43- Technical KPIs (36GOe)

ID	KPI	Unit of Measurement	Formula
36GOeS1	Number of users/customers per market sector	-	
36GOeS2	Market share in different sectors	*% of total number of customers*	$\frac{N_{c,sector}}{\sum_{sector} N_{c,sector}}$
36GOeS3	Number of people employed directly and indirectly as a result of the district heating operation.	-	

Table 44- Social KPIs (36 GOe)

4.9 Cologne Demonstrator (12COe)

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. Globally, RheinEnergie 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 %.
A possible baseline situation that will be considered for the following demonstrator will be referred to a previous oil boiler system (no CHP), providing the same heat provided by the new district heating system.

4.9.1 List of specific KPIs

- Yearly thermal energy production- *MWht/year*;
- Change in yearly thermal energy production with reference to baseline situation- *%;*
- Yearly electric energy production- *MWhe/year*.

Other relevant energetic, environmental, economic and social KPIs that will be calculated for this specific case are included in the table of general KPIs (table 45).

ID	KPI	Unit of Measurement	Formula
12COe1	Yearly thermal energy production	*MWht/year*	$\sum_{year} Q_{CHP}$
12COe2	Change in yearly thermal energy production with reference to baseline situation	*%*	$\frac{\sum_{year}(Q_{CHP} - Q_{baseline})}{Q_{baseline}}$
12COe3	Yearly electric energy production	*MWhe/year*	$\sum_{year} (P_{CHP} - C_{CHP})$

Table 45- Technical KPIs

4.10 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.

4.10.1 List of specific KPIs

- Yearly thermal energy production of each heat pump- *MWht/year*;
- Yearly gas and electric energy consumption of each heat pump- *MWhe/year;*
- COP of each heat pump- *MWhe/year*.

ID	KPI	Unit of Measurement
6COe1	Yearly thermal energy production of each heat pump	*MWht/year*
6COe2	Gas and electricity consumption of each heat pump	*MWh/year and MWhe/year*
6COe3	COP of each heat pump	

5. General KPIs

General KPIs are of relevant importance in order to define common indicators which can summarize in a clear, measurable and communicable way the most important achievements of the Celsius project under the technical, economic, environmental and social point of view.
As reported in the previous paragraphs, the new demonstrators developed in the framework of the Celsius projects have their own specificities and objectives in relation to the specific backgrounds in which they have been conceived and implemented.
The demonstrators cover different aspects related to the development of innovative large scale heating and cooling systems:

- Recovery of waste/renewable energy (CO1, LO2, RO1, RO2, GE1, 7GOe, 8GOe, 9GOe, 11GOe, 19GOe, 20GOe, 12COe, 6COe)
- Storage and load control (GO1, LO2, RO1)
- Development of ICT tools for the optimization of the energy management (RO1, GE1, LO1)
- New applications of the district heating for end-users (GO2, GO3, 29GOe)
- Expansion of the existing district heating network (LO3, RO1, 36GOe)

Beyond the specific aspects analyzed for each implemented smart solution, all the demonstrators developed in the 5 cities of the project aim to significantly reduce CO_2 emissions, developing decentralized energy and district heating and cooling networks and utilizing energy in an efficient way.
Therefore, a common strategy for evaluating impacts at project level is needed in order to enable the learning from a diverse range of situations, supporting the tracing of a Celsius City Roadmap that will be able to support other EU cities in the integration of smart and sustainable heating and cooling systems in relation to the achievement of the EU targets, increasing the potential for replication of the Celsius City Concept in other similar contexts.
To achieve this objective, generic KPIs have been properly identified by following a bottom-up approach, starting from the analysis of each specific demonstrator and then performing a comparative analysis aimed at highlighting common features of the different cases under the identified macro-categories of interest (energetic, environmental, economic and social).
Once the new demonstrators will be in operation, generic KPIs will be calculated for each demonstrator based on the measurements from monitoring.

5.1 Energy indicators

- Yearly amount of thermal energy produced/provided by the new system; this indicator is aimed at providing the size of the different projects, considering the variety of cases developed in the framework of the Celsius project. This parameter is of significant relevance especially for the economic evaluations, stated that economic performances are strictly connected to the size of the different projects;
- Saved primary energy in comparison with baseline situation; this indicator aims at providing an evaluation of the effectiveness of the project with reference to the business as usual situation;
- Energy efficiency of the project: this indicator will be calculated as the ratio between the yearly amount of thermal energy produced/provided by the demonstrator and the primary energy used for the energy production;

- Share of waste/renewable energy: this indicator is particularly significant for all the demonstrators recovering waste heat sources (heat from ventilation shaft and transformers at power substation, heat from the urban waste incinerator, enthalpy in the pressurized natural gas, heat from the sewage network, cooling from river water, cogeneration from wood chips, solar heat to district heating, geothermal heating).

5.2 Environmental indicators

- Yearly GHG savings in comparison with the baseline situation;
- Yearly GHG emissions related to the project;
- Yearly reduction of pollutants emission in comparison with baseline situation;
- Yearly pollutants emission related to the project;
- Ecological and carbon footprint.
  Footprints are aggregated indicators, aimed at quantifying with a single number the impact of a given product or service on the environment, considering its whole life cycle or part of it, in a way similar to what life cycle analysis does. Two of these indicators have been selected as CELSIUS indicators: carbon footprint and ecological footprint.
    - **Carbon footprint** measures the amount of greenhouse gases emissions released to the atmosphere by an organization, a product or a person. As for the ecological footprint and LCA, some simplifications are needed. Carbon footprint is calculated as the carbon dioxide equivalent (CO2e) using the relevant 100-year global warming potential (GWP100). The difference between carbon footprint and the other indicators proposed for assessing greenhouse emissions stays in the consideration (although in a simplified way) of indirect emissions in providing the service: greenhouse gases (GHGs) can be emitted through transport, land clearance, and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings, and services.
    - **Ecological footprint**, measuring the impact of a given system (or product or service) on Earth's ecosystems in terms of biologically productive land and sea area necessary to feed (or to produce or to provide) it. Ecological footprint analysis compares a given system, product or service demand of nature's services with the biosphere's ability to regenerate resources and provide services. For a given service, it does this by assessing the biologically productive land and marine area required to build the machines needed to provide it in their life cycle, to provide the service itself and to absorb the corresponding waste, using prevailing technology. Footprint values at the end of a survey are categorized for carbon, food, housing, and goods and services. Since terrestrial and marine ecosystems have different capacities to produce and provide goods and services around the globe, an average value of productivity of the earth is considered and the "weight" of the given system, product or service is measured into "global hectares" (gha). The reference standard source of conversion factors will be the 2009 standard, available on www.footprintstandards.org

Therefore, footprints will be calculated for all the demonstrators, as regards their operation and with particular care to the use of high impact materials (e.g. refrigerants) and where possible, assessing country specific conversion factors.

5.3 Economic indicators

The evaluation of the economic indicators will be performed based on the economic data provided by the demo responsible partners on the following cost category: investment cost, depreciation time, operating costs, maintenance costs, savings/revenues deriving from the operation of the demonstrator.

- Internal rate of return (IRR) of the new investment;
- Net present value (NPV);
- Yearly depreciation rate per kWh of saved primary energy;
- Yearly depreciation rate per ton of saved CO2e;
- Total cost (yearly depreciation rate + operating costs) per kWh of saved primary energy;
- Total cost (yearly depreciation + operating costs) per ton of saved CO2e.

All indicators shall be **assessed both in presence and absence** of the EU contribution.

5.4 Social indicators

- Number of residents/users benefitting of the new project;
- Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation;
- Variation of working hours per year for O&M of the new system in comparison with baseline situation;
- Internal floor area served by the new system.

A table summarizing the identified general KPIs on energetic, environmental, economic and social aspects and the relative specific cases for which they are relevant is reported below.

	General KPIs	UM	GO1	GO2	GO3	GE1	CO1	LO1	LO2	LO3	RO1	RO2
ENERGETIC	The yearly amount of thermal energy produced/provided by the new system	*kWh/year*	x	x	x	x	x		x	x	x	x
	Saved primary energy in comparison with baseline situation	*kWh/year*	x	x	x	x	x	x	x	x	x	x
	Energy efficiency of the project	*%*	x	x	x	x	x	x	x	x	x	x
	Energy recovery from waste/renewable sources	*kWh/year*	indirect	indirect	indirect	x	x		x			
ENVIRONMENTAL	Yearly GHG savings in comparison with the baseline situation	*%*	x	x	x	x	x	x	x	x	x	x
	Yearly GHG emissions related to the project	*ton $CO_{2\,e}$/year*	x	x	x	x	x	x	x	x	x	x
	Yearly pollutant emissions related to the project	*kg/year*	x	x	x	x	x	x	x	x	Only NOx	Only NOx
	Yearly reduction of polluting emission in comparison to baseline		x	x	x	x	x	x	x	x		
	Carbon footprint	*ton C /year*	x	x	x	x	x	x	x	x		
	Ecological footprint	*ha*	x	x	x	x	x	x	x	x		
ECONOMIC	IRR of the new investment	*%*	x	x	x	x	x	x	x	x		

	Net present value	€	x	x	x	x	x	x	x	x		
	Yearly depreciation rate per kWh of saved primary energy	*€/kWh*	x	x	x	x	x	x	x	x		
	Yearly depreciation rate per ton of saved CO_2e	*€/t CO_2e*	x	x	x	x	x	x	x	x		
	Total cost (yearly depreciation rate + OPEX) per kWh of saved primary energy	*€/kWh*	x	x	x	x	x	x	x	x		
	Total cost (yearly depreciation + OPEX) per ton of saved CO_2e	*€/t CO_2e*	x	x	x	x	x	x	x	x		
SOCIAL	Number of residents/users benefitting of the new project		x	x		x	x	x	x	x		
	Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation		x	x	x	x	x	x	x	x		
	Variation of working hours per year for O&M of the new system in comparison with baseline situation	*hours/year*			x	x	x	x	x	x		
	The internal floor area served by the new system	m^2	x		x	x	x		x	x		

Table 46- General KPIs for the Celsius project: new demonstrators

	General KPIs	UM	9GOe	29GOe	19GOe	11GOe	20GOe	8GOe	7GOe	36GOe	12COe	6COe
ENERGETIC	The yearly amount of thermal energy produced/provided by the new system	*kWh/year*	x	x	x	x	x	x	x	x	x	x
	Saved primary energy in comparison with baseline situation	*kWh/year*	x	x	x	x	x	x	x	x	x	x
	Energy efficiency of the project	*%*	x	x	x	x		x	x	x	x	x
	Energy recovery from waste/renewable sources	*kWh/year*	x	x	x	x	x	x	x	x	x	x
ENVIRONMENTAL	Yearly GHG savings in comparison with the baseline situation	*%*	x	x	x	x	x	x	x	x	x	x
	Yearly GHG emissions related to the project	*ton CO_{2e}/year*	x	x	x	x	x	x	x	x		
	Yearly pollutant emissions related to the project	*kg/year*	x	x	x	x	x	x	x	x		
	Yearly reduction of polluting emission in comparison to baseline		x	x	x	x	x	x	x	x		
	Carbon footprint	*ton C/year*	x	x	x	x	x	x	x	x	x	x
	Ecological footprint	*ha*	x	x	x	x	x	x	x	x	x	x
ECONOMIC	IRR of the new investment	*%*	x	x	x	x	x	x	x	x		

	Net present value	€	x	x	x	x	x	x	x	x		
	Yearly depreciation rate per kWh of saved primary energy	*€/kWh*	x	x	x	x	x	x	x	x	x	
	Yearly depreciation rate per ton of saved CO_2e	*€/t CO_2e*	x	x	x	x	x	x	x	x	x	
	Total cost (yearly depreciation rate + OPEX) per kWh of saved primary energy	*€/kWh*	x	x	x	x	x	x	x	x	x	x
	Total cost (yearly depreciation + OPEX) per ton of saved CO_2e	*€/t CO_2e*	x	x	x	x	x	x	x	x	x	x
SOCIAL	Number of residents/users benefitting of the new project		x	x	x	x	x	x	x	x	x	x
	Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation		x	x	x	x	x			x		
	Variation of working hours per year for O&M of the new system in comparison with baseline situation	*hours/year*	x			x	x	x	x	x		
	The internal floor area served by the new system	*m^2*	x	x	x	x	x	x	x	x	x	x

Table 47- General KPIs for the Celsius: existing demonstrators

celsius
smart cities

6. Conclusions

The Celsius project aims at developing, optimizing and promoting smart decentralized heating and cooling networks 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.

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

In this sense, the set-up of key-performance indicators is of crucial importance in order to summarize the main achievements of the different demonstrators and communicate them to stakeholders, customers and public authorities in the most effective way.

In the present document, the common working methodology followed for the definition of the KPIs has been defined and then applied to each specific case. In particular, the technical solutions implemented in each demonstrator have been analyzed in order to highlight the main innovative elements of concern, by identifying the correspondent business as usual situation.

The application of the defined methodology has allowed the identification of specific energetic, environmental, economic and social KPIs for each demonstrator included in the project.

Moreover, common generic KPIs have been properly identified by following a bottom-up approach, aimed at highlighting the common features of all the different demonstrators, setting-up a strategy for providing a quantitative evaluation of the impacts 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

$G_{B,i}$: 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)]
$T_{gas,\ DHM}$: 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, [€]
$E_{el\ grid}$: Emission factor for each considered pollutant based on the average Italian electric grid emission; [Kg/kWhe]
E_{elCHP}: : Emission factor for each considered pollutant related to electric energy produced by CHP; [Kg/kWhe]
$E_{elTE:}$ Emission factor for each considered pollutant related to electric energy produced by the turbo-expander; [kg/kWhe]
E_{thCHP}: Emission factor for each considered pollutant related to thermal energy produced by CHP: [kg/kWht]
Eboiler: Emission factor for each considered pollutant associate to existing gas fired boilers [kg/Nm^3]
$G_{b,i\ baseline}$: Gas consumption in existing boilers (i) the baseline situation [Nm^3/year]

GO1

$Q_{mix,\ DH}$: 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]

$T_{th,\ end\text{-}user}$: 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]
$Q_{baseline}$: Thermal energy consumption in the baseline situation, [kWh/m^2 year]
$T_{e,in\ baseline}$: average indoor temperature in the baseline situation, [°C]

GO2
$Q_{wg,i}$: 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]
$N_{w,\ j}$: Number of washes, [-]
tw: Time for a washing cycle, [Minutes]
td: Time for a drying cycle, [Minutes]
$T_{el,\ end\text{-}user}$: Tariff for electric energy consumption paid by the end-users, [€/kWhe]
$T_{th,\ end\text{-}user}$: Tariff for thermal energy consumption paid by end-users, [€/kWht]
$E_{el\ grid}$: Emission factor for each considered pollutant based on the average Swedish electric grid emission; [Kg/kWhe]
E_{DHmix}: Emission factor for each considered pollutant associated to the district heating mix; [kg/kWht]
$C_{wg,i\text{-}baseline}$: electric energy consumption for machines (i) in the baseline situation- kWhe

GO3
Q_{sh}: Heat delivered to ship from the district heating system, [kWht]
V_{oil}: Oil consumption in harbour for heating purposes, [lt]
$V_{oil,baseline}$: Oil consumption in the baseline situation, [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]
E_{DHmix}: Emission factor for each considered pollutant associated to the district heating mix; [kg/kWht]
$T_{el,\ DHM}$: Tariff for the electricity consumption paid by the district heating network manager, [€/kWhe]
$T_{th,\ end\text{-}user}$: 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
$C_{hp,\ i}$: 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]
$Q_{st\text{-}dist,\ j}$: 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]
$T_{th,\ end\text{-}user}$: Tariff for thermal energy consumption paid by civil end-users (schools, swimming pool) connected to the new system, [€/kWht]
$T_{gas,\ end\text{-}user}$: 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
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]

$P_{real,s}$: 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]
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
$C_{hp,\ A}$: 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]
$T_{th,\ end\text{-}user}$: 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
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
$Q_{WWTP,HH}/Q_{WWTP,WWTP}$: 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
$Q_{CHP:}$ 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]
$Te_{s,\ DH:}$ 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]
$I_{biofuel}$: 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
Q_{agreem}: Total thermal energy delivered by the district heating to buildings with agreements, [MWht]
$Q_{agreem,\ ref\text{-}i}$: Thermal energy delivered to representative buildings with agreements, [MWht]
$Q_{baseline,\ ref\text{-}i}$: District heating delivered to buildings before having signed the agreements, [MWht]
$Te_{indoor,\ ref\text{-}i}$: Indoor temperatures, [°C]
$Q_{mix,DH}$: District heating production mix, [MWh and % composition]
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 , [€]
$T_{th,\ end\text{-}user}$: Tariff for thermal energy with climate agreements in five representative buildings, [€/kWht]
$T_{th,\ end\text{-}user,\ baseline:}$ Tariff for thermal energy (delivered to customer) in five representative buildings before having climate agreements, [€/kWht]

19GOe
$Q_{c,\ DC}$: 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]
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

$Q_{r,DC}$: 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]
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

$Ts_{,SC}$: 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, [m²]
Dir: Direction, [(point of compass)]
Deg: Tilt angle, [°]
C: Electric energy consumption, [MWhe]
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

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]
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

$Q_{rec,DH}$: 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]
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

$Q_{f, DH}$: 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]
$T_{th, end-user}$: 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
Q_{CHP}: Thermal energy produced by the CHP; [MWht]
P_{CHP} Electric energy produced by the CHP and delivered to the grid; [MWhe]
C_{CHP}: Electric energy consumed by the CHO; [MWhe];
V_{gas} : Biogas/gas consumption
Oc: Operating costs; [€]
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]
Oc: Operating costs; [€]
Dc: Depreciation costs [€]