

E2District

Deliverable 1.3

Report on KPIs and monitoring strategy for district heating and cooling



Dissemination Level: PU

This project is partially funded by the European Commission under the H2020 Framework Programme - Grant Agreement no. 696009

Project Number	:	696009
Project Title	:	Energy Efficient Optimised District Heating and Cooling – E ² District
Deliverable Dissemination Level	:	PU

Deliverable Number	:	D1.3
Title of Deliverable	:	Report on KPIs and monitoring strategy for district heating and cooling
Nature of Deliverable	:	Report
Internal Document Number	:	E2D_D1.3_WP1
Contractual Delivery Date	:	M6-06/30/2016
Actual Delivery Date	:	March 2017
Work Package	:	WP1
Author(s)	:	Stephane Couturier
Total number of pages	:	24
(including cover)		

Abstract
This document is the report on the KPIs and monitoring strategy for the energy savings and performance evaluation of the District Optimization Framework.

Keyword list
District heating and cooling network, Performance, Key performance indicator



Document History

Date	Revision	Comment	Author/Editor	Affiliation
19/10/2016	V0.1	Creation	S. Couturier	VERI
4/11/2016	V0.2	Comments and content modifications	Kostas Kouramas, Giorgio Manganini	UTRC-I
16/11/2016	V0.3	Content modifications	CIT	CIT
22/12/2016	V0.4	Content modifications	CIT	CIT
24/02/2017	V1.0	Content modifications	Kostas Kouramas, Marcin Cychowski	UTRC-I/CIT

Executive Summary

The E²District objective is to optimize design and operation (technical and commercial) of the heating network in order to improve its energy, environmental and economic efficiency, and therefore improve mutual economic profit between DH manager, DH operator, subscriber and end-user. In order to achieve this objective, E²District will develop and demonstrate i) a flexible District Operating System (DOS) for the efficient, replicable and scalable deployment of DHC monitoring, intelligent control, optimization and prosumer engagement and analytics tools, ii) a District Simulation Platform (DSP) of numerical models and production asset optimization tools, and iii) business models enabling the design, retrofit and operation of new flexible assets.

The objective of this deliverable D1.3 is to define operational and maintenance KPIs (DHN efficiency, carbon footprint, quality of service, ROI etc.) and also to define KPIs for the estimation of energy and CO₂ savings regarding the project target (reduce the energy consumption of space and water heating by 30% compared to today's level). These KPIs will be used to validate and assess the DOS and DSP platforms, and their underlying tools and therefore they must be defined to give reliable information about the performance of the DHC system.

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1 Introduction

A Key Performance Indicator is a value used for achieving top operational performance. The relevant performance indicators are identified and prioritized for every domain (technical, environmental, economic and quality of service). They constitute a measure and will be the basis for the performance assessment of the tool.

The objective of this deliverable D1.3 is to define operational and maintenance performance KPIs in the following main domains:

- Technical performance (DHN efficiency with several indicators, cogeneration performance, electrical consumption, maximum ratio of heat power demand).
- Environmental performance (carbon footprint, ratio of renewable energy and heat recovery, factor of primary resources).
- Quality of service (heat power interruption rate, comfort evaluation, flexibility rate of substations) in order to assess the global service to the client.
- Social behavior in order to estimate the average intention of building occupant to act up with demand response constraints. To estimate the expected impact behavior demand response has on the overall operation of the system.
- Economic performance (total cost of heat production, levelized cost of energy, gross margin, sale margin ratio, ROI).

After an overall presentation of the different KPIs (objective, formula, monitoring and data needed), each KPI is presented in detail based on:

- The different stakeholders involved for each KPI
- The different frequencies of KPI analysis which give information about the monitoring needed
- The development into the functional architecture for each work area of the project (Deliverable D1.1: Report on requirements for district heating and cooling). The different work areas and the different functions of the project are given in detail in deliverable D1.1, *Report on the requirement of district heating and cooling*, and are summarized in appendix.

The KPIs presented can be used by different stakeholders with different periods of analysis (day, month, year). The KPI can be calculated at each time step but the KPI can be re-evaluated with a different time interval (for example, the CO₂ emission can be computed each day and cumulated day after day in order to evaluate the value at the end of the heating season). The time interval over which the KPIs are calculated will be defined and adapted in WP4. The KPIs used by the DH manager are the KPIs which must be used to validate the energy savings obtained with the different scenarios, these are the main KPIs which validate the project.

This document is organized as follows. First a global set of Key Performance Indexes (KPIs) that can be potentially used for the assessment of various performances of districts is presented in Section 2, where the KPIs and associated formulas are described in detail. Then in Section 3 the necessary variables and measurements that are needed to calculate those KPIs are detailed. Finally, in Sections 4 – 8 we present the relevance and implementation of the proposed KPIs to each work area and the relation to the E2District stakeholders. The document concludes with a summary of the objectives of the document and the relation of the KPIs to the rest of the work of the project.



2 List of Key Performance Index

The different KPIs are presented on four axes: technical, economic, environmental and quality of service (Table 1) in order to achieve the objectives of the project. Most of these KPIs are current KPIs to assess DHC performance. All KPIs are based on different studies [3-4-5-6-7-8] and also come from all partner's expertise.

KPI	Abbreviation	Unit
Technical KPIs		
Global thermal efficiency	KPI_GTE	%
Production thermal efficiency	KPI_PTE	%
Distribution thermal efficiency	KPI_DTE	%
Electrical consumption	KPI_ELC	%
Maximum rate of heat power demand [4]	KPI_PWR	%
Cogeneration availability rate	KPI_COA	%
Cogeneration efficiency	KPI_COE	%
Peak demand flexibility	KPI_PDF	(kW, h)
Environmental KPIs		
CO ₂ emission (district perimeter) [4]	KPI_CO2D	Kg CO ₂ /kWh
CO ₂ emission (building perimeter) [4]	KPI_CO2B	Kg CO ₂ / kWh
Ratio of renewable energy & heat recovery	KPI_RRE	%
Primary resource factor [6]	KPI_FPR	–
Quality of service KPIs		
Flexibility rate of substations	KPI_FLEX	%
Indoor temperature	KPI_INT	%
Heat power interruption rate [4]	KPI_IRS	%
Social KPIs		
Aggregated Intention to Act	KPI_ITA	%
Expected BDR (Building Demand Response) Impact	KPI_EI	kWh
Economical KPIs		
Total energy cost [3]	KPI_ENC	€/MWh
Gross margin [3]	KPI_GRM	€/MWh
Sale margin [3]	KPI_SAM	€/MWh
LCOE (Levelized Cost Of Electricity) [7-8]	KPI_LCE	€/MWh
LCOH (Levelized Cost Of Heat) [7-8]	KPI_LCH	€/MWh
NPV (Net Present Value) [6]	KPI_NPV	€

Table 1: List of KPIs abbreviations

Here we define the peak demand flexibility with the flexibility power (kW) available and the duration of flexibility action (h). The peak demand flexibility must take into account the storage and the buildings flexibility (computed in BF02 [1]).



Figure 1 is presented to clearly identify the energy flows measured in a DHCN and used in the different KPI formulae.

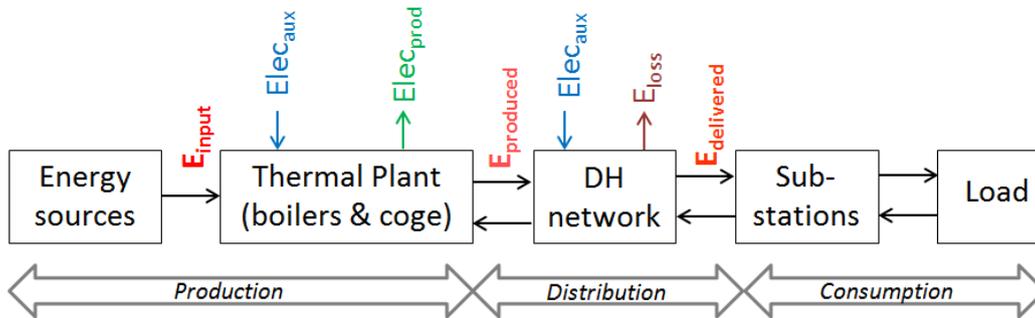


Figure 1 Schematic representation of energy flows in DHCN perimeter *

*: in Figure 1, **E**: Thermal energy. **Elec** : Electrical energy

KPI and objective	Formula
Technical KPIs	
Global thermal efficiency (KPI_{GTE}) : To estimate the global energy performance (input/output)	$\frac{\text{Energy delivered (MWh)}}{\text{Fuel input to the heating plant (MWh LHV)}} \times 100$
Production thermal efficiency (KPI_{PTE}) : To estimate the boilers efficiency	$\frac{\text{Energy produced (network departure, in MWh)}}{\text{Fuel input to the heating plant (MWh LHV)}} \times 100$
Distribution thermal efficiency (KPI_{DTE}) : To estimate the thermal losses of the distribution loop	$\frac{\text{Energy delivered (MWh)}}{\text{Energy produced (MWh)}} \times 100$
Electrical consumption (KPI_{ELC}) : To estimate the electrical needs for the heat production	$\frac{\text{Electrical consumption of auxillary (MWh)}}{\text{Energy delivered (MWh)}} \times 100$
Maximum ratio of heat power demand (KPI_{PWR}) : To estimate the maximum heat power demand at the base temperature	$\frac{\text{Maximum of heat power demand for the base temp * (kW)}}{\text{Maximum heat power of the central plant (kW)}} \times 100$
Cogeneration availability rate (KPI_{COA}) :	$\frac{\text{Electricity produced (MWh)}}{\text{Power garanted (contract, MW) \times Number of running hours(h)}} \times 100$
Cogeneration efficiency (KPI_{COE}) :	$\frac{\text{Energy produced (Electricity + thermal) (MWh)}}{\text{Energy input (MWh LHV)}} \times 100$

Table 2: List of Key Performance Index for a technical analysis

*: Maximum of heat power demand (base temperature) = $P_{\text{max measured}} \times \left(\frac{18 - T_{\text{outdoor}}^{\text{base}}}{18 - T_{\text{outdoor}}^{\text{measured}}} \right)$

Regarding the technical aspect for the demonstration district, the energy savings which will be validated according to the International Performance Measurement and Verification Protocol (IPMVP) [2] because it is the well-known standard to create a baseline for the heat consumption. It comes from the task 5.1 of the project (Baseline definition for the demonstration district) and will be presented later in detail in WP5.





KPI and objective	Formula
Environmental KPIs	
CO₂ emission (district perimeter), KPI_{CO2D}: To estimate the CO ₂ emission regarding the energy production of the heating plant	$\frac{\text{Quantity of CO}_2 \text{ released (kg CO}_2\text{)}}{\text{Fuel input to the heating plant (kWh LHV)}} \text{ (kg CO}_2\text{/kWh)}$
CO₂ emission (building perimeter), KPI_{CO2B}: To estimate the CO ₂ emission regarding the energy delivered to the substations	$\frac{\text{Quantity of CO}_2 \text{ released (kg CO}_2\text{)}}{\text{Energy delivered (kWh)}} \text{ (kg CO}_2\text{/kWh)}$
Ratio of renewable energy & heat recovery (KPI_{RRE})	$\frac{\text{Renewable and recuperation energy (MWh)}}{\text{Energy produced (MWh)}} \times 100 \text{ (\%)} $
Primary resource factor (KPI_{FPR}): Estimation of the primary resources used par MWh delivered	$\frac{\sum_i Q_{F,i} \times f_{P,\text{fuel}}(\text{MWh}) - W_{\text{CHP}} \times f_{P,\text{elt}}(\text{MWh})}{\text{Energy delivered (MWh)}}$ <p>With: Q_{F,i}: Total input fuel to district heating system (fuels of district heat and auxiliary electrical consumption) f_{P,F,i}: Primary resource factor delivery to the considered system i W_{CHP}: Electricity production of the cogeneration plant f_{P,elt}: Primary resource factor of electrical power</p>

Table 3: List of Key Performance Index for an environmental analysis

KPI and objective	Formula
Quality of service KPIs	
Flexibility rate of substations (KPI_{FLEX}) To estimate the weight of the flexibility action in comparison to the total heat power subscribed	$\frac{\sum_{i=1}^n (\text{flexibility period in hour}) \times (\text{Heat power subscribed of the substation})}{\text{Running period (hours)} \times \text{Total subscribed Heat Power}} \times 100$ <p>With If the Heat power subscribed is not available, the maximum heat power demand is considered (values of the previous season)</p>
Indoor temperature (KPI_{INT}): To estimate the comfort degradation	$(\text{Duration of all events} / \text{duration of the analysis period}) \times 100$ <p>With Generation of an invent if T_{indoor} < Comfort temperature (to be defined) The event ends when T_{indoor} ≥ Comfort temperature</p>
Heat power interruption rate (KPI_{IRS}) To estimate the available power rate of the substations in comparison to the total power subscribed	$\frac{\sum_{i=1}^n (\text{interruption period in hour}) \times (\text{Heat power subscribed of the substation})}{\text{Running period (hours)} \times \text{Total subscribed Heat Power}} \times 100$

Table 4: List of Key Performance Index to estimate the quality of service

Table 5 presents the Aggregated intention to act (KPI_{ITA}) and the Expected BDR impact (KPI_{EI}) regarding the flexibility actions. The Goals are obtained with the function BF02b (Calculation of secondary HN building flexibility potential).

KPI and objective	Formula
Social KPIs	
Aggregated Intention to Act (KPI_{ITA}) To estimate the average intention of building occupant to act upon supply side constraints	$\frac{\sum_{j=1}^{\#Individuals} \sum_{i=1}^{\#Goals} \text{Intention}[\text{Goal}_i, \text{Individual}_j]}{\#Individuals \times \#Goals}} \times 100$
Expected BDR Impact (KPI_{EI}) To estimate the expected impact behavior demand response has on the overall operation of the system	$\frac{\sum_{j=1}^{\#Individuals} \sum_{i=1}^{\#Goals} \text{Intention}[\text{Goal}_i, \text{Individual}_j] \times \text{Impact}[\text{Goal}_i]}{\#Individuals \times \#Goals}}$



Table 5: List of Social Key Performance Indicators

KPI and objective	Formula
Economic KPIs	
Total energy cost (€/MWh), KPI_{ENC} To use for a comparison between different scenarios	$\frac{\text{Operational cost (OpEx in €)}}{\text{Energy delivered (MWh)}}$ <p>With : OpEx = Salaries + All salary related social cost + Maintenance costs + External service costs + Rents and leases + Administration</p>
Gross margin (€/MWh), KPI_{GRM} To use for a comparison between different scenarios	$\text{Total revenues (€/MWh)} - \text{Total cost (€/MWh)}$ <p>With Total revenues = heat revenues (incomes from heat sales) + electrical revenues (incomes from electrical sales) + other revenues (CO₂ quotas and subventions) Total cost = OpEx cost + Fuel cost (fuel and heat purchase, and fuel transportation (include. capacity fees) + other fuel related direct cost</p>
Sale margin (%), KPI_{SAM} To use for a comparison between different scenarios	$\frac{\text{Total revenues (€/MWh)}}{\text{Total cost (€/MWh)}}$ <p>See explanation of total revenues and total cost below</p>
LCOE : Levelized Cost Of Electricity (KPI_{LCE}). To estimate the total cost of electricity on the equipment lifetime used	$\frac{\sum_{i=1}^{nl} \frac{\text{Invest}_i^E + \text{OpEx}_i^E + \text{Fuel cost}_i^E}{(1+r)^i}}{\sum_{i=1}^{nl} \frac{\text{Electricity produced}_i}{(1+r)^i}}$ <p>With E : corresponding to electricity i: year nl : life duration of the system Fuel cost = fuel and heat purchase, and fuel transportation (include. capacity fees)</p>
LCOH : Levelized Cost Of Heat (KPI_{LCH}). To estimate the total cost of heat on the equipment lifetime used	$\frac{\sum_{i=1}^{nl} \frac{\text{Invest}_i^H + \text{OpEx}_i^H + \text{Fuel cost}_i^H}{(1+r)^i}}{\sum_{i=1}^{nl} \frac{\text{Heat produced}_i}{(1+r)^i}}$ <p>With H : corresponding to heat i: year nl : life duration of the system Fuel cost = fuel and heat purchase, and fuel transportation (include. capacity fees)</p>
NPV calculation (KPI_{NPV}): To estimate if the investment is profitable	$\text{Investment} + \frac{\text{CF}_1}{(1+r)^1} + \dots + \frac{\text{CF}_n}{(1+r)^n}$ <p>With Investment : total investment cost (<0) n : number of years for the investment CFn : cash flow from year n related to the investments (annual financial gains related to the investments - annual amortization) r : cost of capital (actualization rate)</p>

Table 6: List of Key Performance Index for economic analysis

3 Data and monitoring needed for KPIs calculation

To compute the different KPIs, variables from monitoring and other data (such as technical, environmental or economic data) are required, such as:

- Grid calculation for CO₂ emission



- Primary resource factor
- Economic data: heat and electrical revenues, OpEx cost, investment cost
- Total subscribed heat power for each substation

All these data, which are needed to compute the formulae presented in the previous tables, are defined and obtained in functions DF01 (Data collection and check) and OF01 (Data collection (Real Time and Historical)) of the work area (cf. Appendix and [1]). The variable and data requirements for the calculation of the DHC KPIs are summarized in the following sub-sections.

3.1 Variable requirements for KPI computation

Except for the social KPI, the variables needed for KPIs computation are common variables because they are related to the energy consumption and production (heat and electricity). For the time steps, the ideal setting is a little time step (magnitude of order of few minutes to well defined the flexibility behavior).

System	Variables	Time step	KPI				
			Technical	Environmental	Economical	Quality of service	Social
Boilers	Energy and power	10 minutes (1 minute if possible)	x				x
	Energy input (kWh LHV)		x	x	x		x
	Interruption period (hour)					x	
Renewable and recuperation energy	Energy and power available	Hour or less	x				x
Cogeneration	Heat production	Hour or less	x				x
	Electricity production		x	x	x		x
	Energy input (kWh LHV)		x	x	x		x
	Number of running hour		x				x
All auxiliary (pump, valve,...) for production and energy distribution	Electrical consumption	Hour or less	x				
Substations	Energy delivered	10 minutes (1 minute if possible)	x	x	x	x	x
	Number of running hour						x
Buildings	Indoor temperature	10 minutes (but can depend on sensor)	x			x	x
	Window state						x
	Door state						x
	Heat appliance settings						x
	Occupancy						x
	Humidity						x
	CO2						x
Other	Outdoor temperature	10 minutes	x				



Table 7: Variable needed for the KPIs computation

The list of variables required for KPI computation presented in Table 7 is intended to be an exhaustive list for the measurement data (additional data are required – table 8). For cooling systems, data and equipment are not presented but variables listed here are generic for KPIs computation (also for cooling).

For the Social KPI, the model to estimate the intention to act regarding the flexibility is not defined yet because it can depend on many operating parameters and also on occupant behavior. At this stage, we keep all variables for this KPI and the flexibility results will help us to define the variables needed which can be less as those proposed in table 7, for social KPI. All of these readings from the building will be used to calibrate the behavioral model. Both, to estimate the individual's intention to act by measuring people's reaction to our BDR triggers, as well as to generate context for these triggers.

3.2 Additional Data requirements for KPI computations

Technical KPIs	Maximum heat power of the central plant (kW) <i>All boilers and CHPS are taken into account if those are full dedicated to the district heating</i>
Environmental KPIs	Database to compute CO ₂ emission according to the type of fuel Database of primary resource factor according to the type of fuel
Economical KPIs	<p><u>Revenues:</u></p> <p>Heat revenues (incomes from heat sales, €/MWh)</p> <p>Electrical revenues (incomes from electrical sales, €/MWh)</p> <p>Other revenues (CO₂ quotas and subventions, €/MWh)</p> <p>Fuel cost and heat purchase, and fuel transportation (incl. capacity fees). And other fuel related direct costs. In €/MWh.</p> <p><u>For OpEx calculation:</u></p> <p>Personnel cost: Salaries/wages and all salary related social costs</p> <p>Other operational costs: Maintenance costs, external service costs, rents and leases. Administrations cost.</p> <p><u>For Investment calculation:</u></p> <p>Investment cost</p> <p>Number of year for the investment</p> <p>Cash flow from year n related to the investments</p> <p>Cost of capital (actualization rate)</p>
Quality of service KPI	Heat power subscribed for each substation
Social KPI	Additional Survey Data

Table 8: Data needed for the KPIs calculation



For the Social KPI, at this stage, it is not well defined and maybe an additional survey will be needed to pre-calibrate certain variables of the behavior model. This is necessary for bootstrapping the operation before significant self-learning has occurred, for generating input data for our learning algorithm, as well as for validating the correctness of our algorithms.



4 Technical KPIs

The technical KPI must be a relevant indicator to evaluate the operational performance in order to optimize it. Relevant performance levers can be identified and prioritized for every domain (technical, environmental, economic, quality of service). They constitute a guideline for evaluation of the DHN performance and will be the basis for the performance assessments, to compare for example different scenarios.

In Table 9, the stakeholders involved with the different KPIs are presented and some stakeholders are not concerned with technical KPI. The frequencies of analysis are the recommended time periods to analyze the KPIs which can be used to control the DHCN, to organize maintenance operations or to make an overall analysis of the DHCN (reporting).

Table 9 lists the technical KPIs for a DHCN system, and describes the associated stakeholders, the related different frequencies of analysis and the related functions of the E2District architecture (see Appendix and [1]) where these KPIs will be used. More specifically, the technical KPIs will be used in the following functions of the E2District functional architecture:

- DF07: Automatic standard report (Design of primary heating network)
- OF07: Real time dashboard (Operation of primary heating network)
- OF08: Automatic reports (Operation of primary heating network)

Name	KPI	Stakeholders involved							Frequencies of analysis					KPI use			Related Functions [1]	
		DH manager	DH operator	Subscriber	End-user	Local & National authority	DH Owner	Investors	General contractor & designer	Instantaneous	Daily	Weekly	Monthly	Yearly	Operating	Maintenance		Reporting
Global thermal efficiency	KPI_GTE	x											x	x			x	DF07/OF08
			x							x	x				x	x		OF07/OF08
Production thermal efficiency	KPI_PTE	x										x	x	x			x	DF07/OF08
			x							x	x				x	x		OF07/OF08
Distribution thermal efficiency	KPI_DTE	x											x	x			x	DF07/OF08
			x								x	x			x	x		OF08
Electrical consumption	KPI_EC	x											x	x			x	DF07/OF08
			x											x		x		OF08
Maximum rate of heat power demand	KPI_PWR	x												x	x		x	DF07/OF08
			x											x	x		x	OF07/OF08
								x	x					x				
Cogeneration availability rate	KPI_COA		x										x	x				OF08
		x						x	x					x			x	DF07/OF08
Cogeneration efficiency	KPI_COE		x												x		x	OF07/OF08
		x												x			x	DF07/OF08

Table 9: Perimeter of the Technical KPIs



5 Environmental KPIs

The environmental KPI must be a relevant indicator to evaluate the environmental performance: CO₂ emission, ratio of renewable energy and recovery heat and the energy primary resources used per MWh delivered. For the CO₂ emission analysis, we only focus on the heat production during the running period.

In Table 10, the stakeholders involved with the different KPIs are presented and some stakeholders are not concerned with technical KPI. The frequencies of analysis are the recommended time periods to analyze the KPIs which can be used to control the DHCN, to organize maintenance operations or to make an overall analysis of the DHCN (reporting).

The environmental KPIs are listed in Table 10 which again describes the associated stakeholders, the related different frequencies of analysis and the related functions of the E2District architecture (see Appendix and [1]) where these KPIs will be used. The environmental KPIs will be used in the following functions of the E2District functional architecture:

- DF07: Automatic standard report (Design of primary heating network)
- OF07: Real time dashboard (Operation of primary heating network)
- OF08: Automatic reports (Operation of primary heating network)

Name	KPI	Stakeholders involved								Frequencies of analysis					KPI use			Related Functions [1]
		DH manager	DH operator	Subscriber	End-user	Local & National authority	DH Owner	Investors	General contractor & designer	Instantaneous	Daily	Weekly	Monthly	Yearly	Operating	Maintenance	Reporting	
CO ₂ emission (district perimeter)	KPI_CO2D	x				x		x	x					x			x	OF08/DF07
CO ₂ emission (building perimeter)	KPI_CO2B	x				x		x	x					x			x	OF08/DF07
Ratio of renewable energy & heat recovery	KPI_RRE					x		x	x					x			x	OF08/DF07
			x								x	x		x	x			OF08
		x											x	x			x	OF08/DF07
Primary resource factor	KPI_PRF		x													x		OF08
		x										x	x			x	OF08/DF07	
						x		x	x					x			x	OF08/DF07

Table 10: Perimeter of the Environmental KPIs

6 Quality of service KPI

The following table presents the perimeter of the different KPIs to evaluate the quality of service: the subscribers involved, the different frequencies of analyses and the KPI use. A second level of information is the KPI use into the project functional architecture:

- BF03: Indicator calculation (Group of network buildings)
- OF07: Real time dashboard (Operation of primary heating network)



Name	KPI	Stakeholders involved							Frequencies of analysis					KPI use			Related Functions [1]	
		DH manager	DH operator	Subscriber	End-user	Local & National authority	DH Owner	Investors	General contractor & designer	Instantaneous	Daily	Weekly	Monthly	Yearly	Operating	Maintenance		Reporting
Flexibility rate Substation	KPI_FLEX		x								x	x			X			BF03
		x			X								X	X			x	BF03
				x				x							X			x
Comfort (Indoor temperature)	KPI_INT		x							x	x				X			BF03
		x		x	x								x				x	BF03
Heat power interruption rate	KPI_IRS	x	x											x		x	x	OF07

Table 11: Perimeter of the Economic KPIs

Comfort is very subjective so, it is very difficult to determine the level of comfort with accuracy. Furthermore, it is difficult to have a representative value for the entire building. The objective here, is just to compare two scenarios to detect if there is a risk of comfort degradation. The KPI_INT can be used to compare two scenario, if the KPI value increase, the thermal comfort decrease because the comfort temperature is not reached (the comfort temperature can be fixed to 20°C for example). This KPI can be used if the indoor temperature is not monitored.

7 Social KPI

The Table 10 outlines the relation between the social KPIs, the stakeholders, the time periods, as well as context and functions.

Name	KPI	Stakeholders involved							Frequencies of analysis					KPI use			Related Functions [1]	
		DH manager	DH operator	Subscriber	End-user	Local & National authority	DH Owner	Investors	General contractor & designer	Instantaneous	Daily	Weekly	Monthly	Yearly	Operating	Maintenance		Reporting
Aggregated Intention to Act	KPI_ITA	x				x	x	x					x	x			x	BF02a
Expected BDR Impact	KPI_EI		x	x							x	x			X			BF02a

Table 12: Perimeter of the Social KPIs



8 Economic KPIs

These KPIs constitute a guideline for evaluation of the DHN economic performance. In Table 10, the stakeholders involved with the different KPIs are presented and some stakeholders are not concerned with technical KPI. The frequencies of analysis are the recommended time periods to analyze the KPIs which can be used to control the DHCN, to organize maintenance operations or to make an overall analysis of the DHCN (reporting).

The economic KPIs are listed in Table 10 which again describes the associated stakeholders, the related different frequencies of analysis and the related functions of the E2District architecture (see Appendix and [1]) where these KPIs will be used. The environmental KPIs will be used in the following functions of the E2District functional architecture:

The following table presents the perimeter of the different economic KPIs: the subscribers involved, the different frequencies of analyses and the KPI use. A second level of information is the KPI use into the project functional architecture:

- DF07: Automatic standard report (Design of primary heating network)
- OF08: Automatic reports (Operation of primary heating network)

Name	KPI	Stakeholders involved								Frequencies of analysis					KPI use			Related Functions [1]
		DH manager	DH operator	Subscriber	End-user	Local & National authority	DH Owner	Investors	General contractor & designer	Instantaneous	Daily	Weekly	Monthly	Yearly	Operating	Maintenance	Reporting	
Total energy cost (€/MWh)	KPI_ENC	x	x				x	x						x			x	OF08 DF07
Gross margin (€/MWh)	KPI_GRM	x					x	x						x			x	OF07 DF05
Sale margin (€/MWh)	KPI_SAM	x					x	x						x			x	OF08 DF07
LCOE	KPI_LCE	x					x	x	x					x			x	DF07
LCOH	KPI_LCH	x					x	x	x					x			x	DF07
NPV calculation	KPI_NPV	x					x	x	x					x			x	DF07

Table 13: Perimeter of the Economic KPIs

These KPI are related to the economic analysis. The total energy cost can be used to compare different scenarios which do not require investment. The LCOE coefficient can be used to compare different scenario in a long term engagement (lifespan equipments) and can be coupled with a NPV calculation to determine the profitability of the investments. The gross margin and sale margin are used to determine the benefit produced by the district heating.



9 Conclusion

Many KPIs have been proposed to evaluate DHN operational and maintenance performance in order to well estimate energy and CO₂ savings regarding the key project target. However, as the project progresses with the research on the algorithms and the modules of the project, and the system understanding of the demo-site increases, some of these KPI maybe further refined. For example, more detailed or modified efficiency and energy cost KPIs (described as functions of real physical variables) may be used as objective functions for scheduling optimization and control algorithms that will be developed in WP3, and will be presented in the subsequent deliverables D3.1 and D3.3. Nevertheless, this deliverable defines the KPIs relevant to energy efficient DHCNs and their stakeholders, which can be used to assess the overall performance of a DHCN from various aspects, in the following key areas:

- Technical
- Environmental
- Economical
- Quality of service
- Social Impact

Since the KPIs presented here are a global generic set of the performance measures for district systems, not all of them have to be applicable for all districts. Given that different DHCN systems have different requirements, business models and stakeholder needs, there might be only certain KPIs from the above set that will be relevant to this specific system. Thus, it is difficult to prioritize some KPIs because each information is different and even if there are many KPI, they are not dedicated to all stakeholders and the frequencies of analysis are different (day, week, month or year). During the development and the validation of the District Simulation Platform (WP2), prioritization will be necessary but not at this stage. For the social KPI, the demonstration phase will be used to well define variables of the behavior model. This step with the definition of additional survey data will be used to validate the correctness of our algorithms. The Economic KPIs are defined to give a first economic analysis. For the final decision, a more important economic study will be performed.



10 Appendix: Work areas and functions of E²district

To answer the stakeholders needs, the project has been divided in 4 work areas (Figure 1) with the following objectives:

1. Maximize the network efficiency (energetic, environmental and economic), through its design, answering end-users heat demand and taking into account foreseen innovative operation process
2. Maximize the efficiency of the network (energetic, environmental and economic), through operation within the design perimeter defined before
3. Offer new services to the subscriber and the end-user, especially improving interaction between the operator, the subscriber and the end-user
4. Improve DHCN value proposition to attract investors

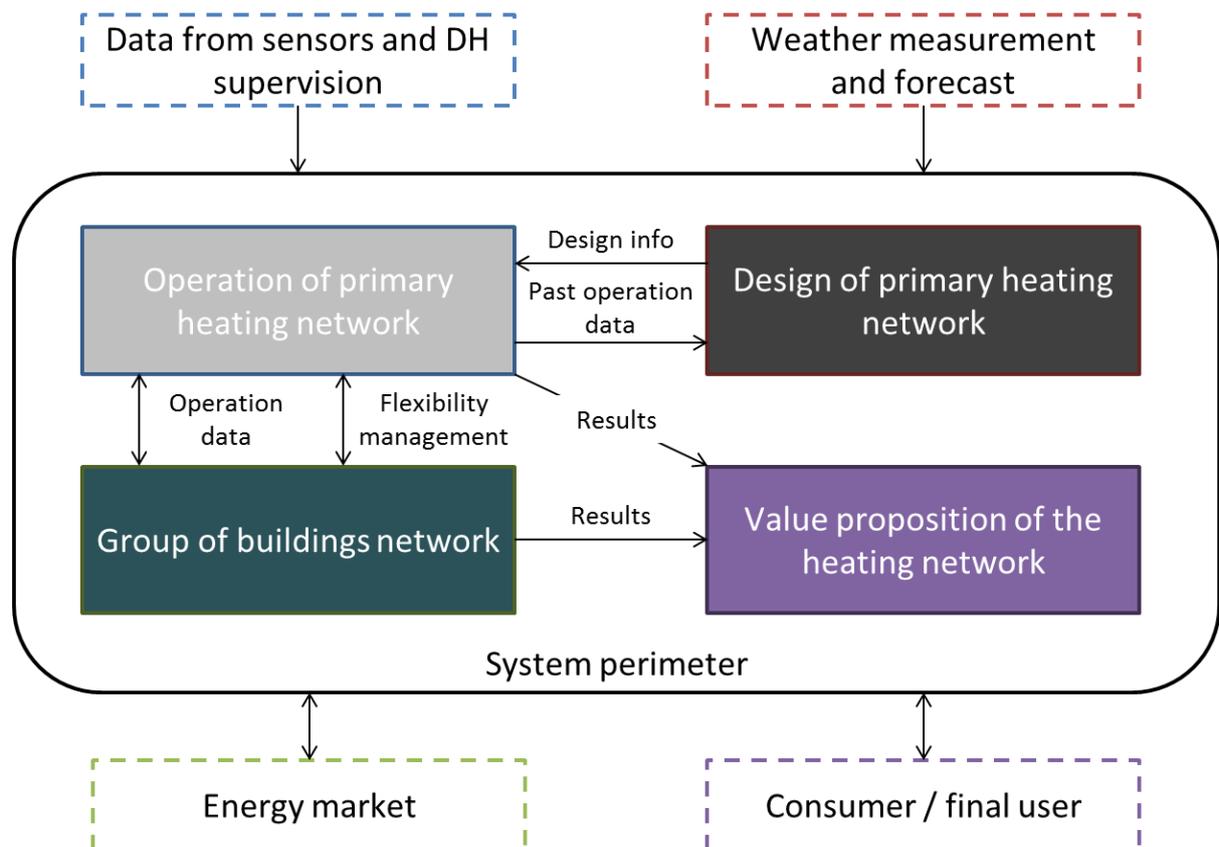


Figure 2 E²District Work Areas

The three main work areas are presented below with the functions which will be developed. For each function: designation, summary and stakeholder(s) involved are presented.



Design of primary heating network

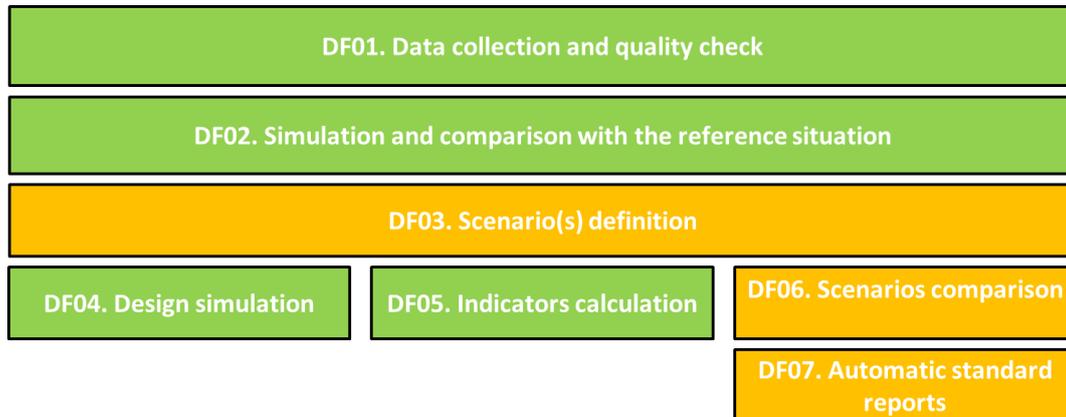


Figure 3 Design of primary heating network functional architecture¹

Ref.	Designation	Summary	Stakeholder(s) involved
DF01	Data collection and quality check	Collect and check data consistency and quality	DHCN manager, DHCN operator, subscriber General Contractor & Designer
DF02	Simulation and comparison with the reference situation	Parameterize and simulate the reference case	General Contractor & Designer
DF03	Scenario(s) definition	Set-up the different configurations to be assessed	
DF04	Design simulation	Calculate the results for each scenario	
DF05	Indicators calculation		
DF06	Scenarios comparison		
DF07	Automatic standard reports	Report the Results of the optimization process; main KPIs are shown	

Table 14 Design of primary heating network functions' list

¹ In green the high level functionalities (explicitly in the proposal, has to be treated in the project) / in orange the secondary level functionalities (Not explicitly described in the proposal, but has to be treated in the project anyway. The way to address this point has to be detailed, as well as the corresponding task)





Operation of primary heating network

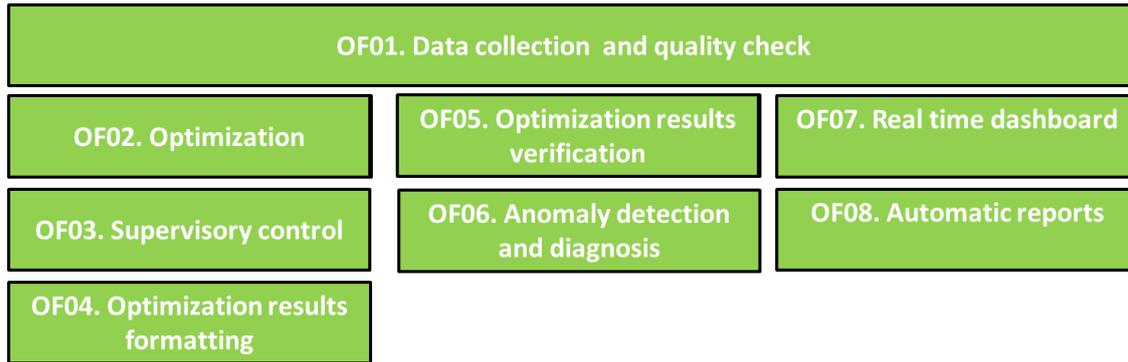


Figure 4 Operation of primary heating network functional architecture

Ref.	Designation	Summary	Stakeholder(s) involved
OF01	Data collection (Real Time and Historical) and quality check	Collect and store all data needed by other OF functions	NA
OF02	Optimization	Calculate the optimal way to operate the DHCN few days ahead from an economical point of view	DHCN Operator
OF03	Supervisory Control	Automatic control system to optimally coordinate different DHCN plant generation equipment (CHP, Boilers, Chillers, thermal storage, etc.) and optimize plant system efficiency	Technology Providers
OF04	Results formatting	Provide access to the stored data	DHCN operator
OF05	Optimization results verification, validation and record	Display results of OF02 and records, allows operator validate the results and record them	DHCN Operator
OF06	Failure Detection and Diagnosis	Detect anomalous performance from nominal system operating conditions.	Technology provider, operator, facility manager, building/system owner.
OF07	Real time dashboard	Visualization of stored data	DHCN operator , manager subscriber
OF08	Automatic reports	Quick abstract of results for periodic report purposes	DHCN operator, Subscriber, end user

Table 15 Operation of primary heating network functions' list



Group of building network

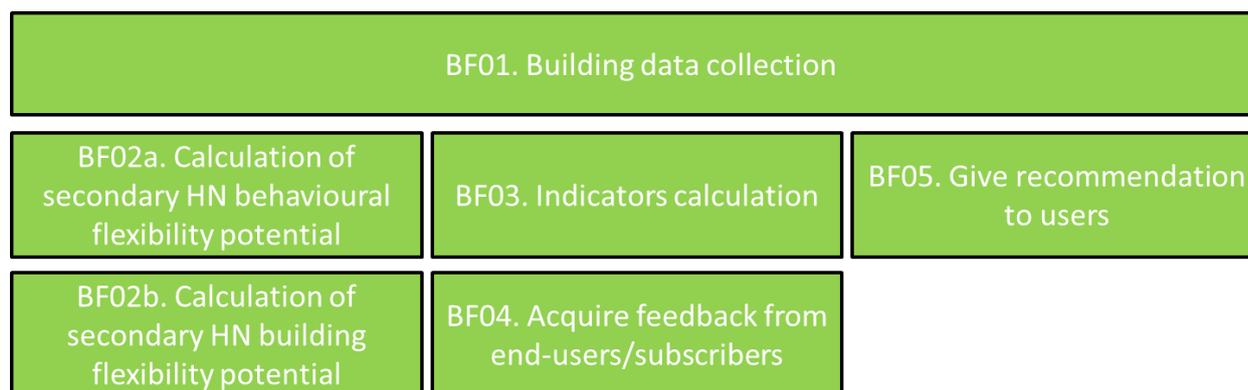


Figure 5 Group of buildings network functional architecture

Ref.	Designation	Summary	Stakeholder(s) involved
BF01	Building data collection	Collect all needed data for other building functions	NA
BF02a	Calculation of secondary HN behavioral flexibility potential	Execution of the behavioural model based on supply side constraints	DHCN operator
BF02b	Calculation of secondary HN building flexibility potential	Calculate the buildings flexibility forecast of implied buildings	End-users Operators
BF03	Indicators calculation	cost, consumption, status, comfort	End-user, operator, manager
BF04	Acquire feedback from end-users/subscribers	Collect calibration data for the behavioural model	DHCN operator, end-user
BF05	Give recommendation to users	Provide action plans to end-users based on the behavioural model	DHCN operator, end-user

Table 16 Group of buildings network functions' list



11 Bibliography

- [1] E2District, "D1.1: Report on Requirements on District Heating and Cooling," 2016.
- [2] IPMVP, "International Performance Measurement & Verification Protocol".
www.ipmvp.org
- [3] Study prepared jointly by ERRA and FORTUM, "Benchmarking District Heating in Hungary, Poland, Lithuania, Estonia and Finland", April 2011.
<https://www.ure.gov.pl/download/1/4419/FORTUMBenchmarkingDHin5countriesERRAFortumApril.pdf>
- [4] Charte des services publics locaux, "Indicateurs de performance pour les réseaux de chaleur et de froid", March 2009.
www.fondation-igd.org/files/pdf/IGD_Indicateurs_Reseau_chaleur.pdf
- [5] Svend Frederiksen and Sven Werner, "District Heating and Cooling", 2014, Studentlitteratur.
- [6] ECOHEATCOOL, Work package 3, "Guidelines for assessing the efficiency of district heating and district cooling system", 2006
https://www.euroheat.org/wp-content/uploads/2016/02/Ecoheatcool_WP3_Web.pdf
- [7] Subsidies and costs of EU energy Annex 4-5
<https://ec.europa.eu/energy/sites/ener/files/documents/DESNL14583%20Final%20report%20annexes%204%205%20v3.pdf>
- [8] Munich Personal RePEc Archive. "Modification of the LCOE model to estimate a cost of heat and power generation for Russia".
https://mpra.ub.uni-muenchen.de/65925/1/MPRA_paper_65925.pdf

