H2020 Work Programme

D4.1 - SO WHAT TOOL KPI PANEL

Lead Contractor: **RINA Consulting (RINA-C)**

Date: 01/06/2021

Project title	Supporting new Opportunities for Waste Heat and cold valorisation Towards EU decarbonization		
Project acronym	SO WHAT	**Start / Duration**	June 2019 (36 months)
Coordinator	RINA Consulting S.p.A.		
Website	www.sowhatproject.eu		

Deliverable details			
Number	4.1		
Title	SO WHAT tool KPI panel		
Work Package	WP4 SO WHAT tool development		
Dissemination level[1]	PU	**Nature**	Report
Due date (M)	30/11/2020	**Submission date (M)**	01/06/2021
Deliverable responsible	Matteo Porta (RINA-C)		

	Beneficiary
Deliverable leader	Matteo Porta (RINA-C)
Contributing Author(s)	Matteo Porta, Oliver Neu
Reviewer(s)	Francesco Peccianti, Nick Purshouse
Final review and quality approval	F. Peccianti (01.06.2021)

Document History			
Date	Version	Name	Changes
14/05/2021	v1		ToC
24/05/2021	v2		IES revision
28/05/2021	V3		RINA-C revision
01/06/2021	v4		final for submission

Executive summary

This report aims to provide the theoretical framework and algorithms for KPIs calculation needed to perform economic, energetic, environmental and social evaluations on the technical options (scenarios) that can be selected by the SO WHAT tool. In particular different aspects are addressed in relation to the different domains in order to provide the end-user with a number of quantitative and qualitative indicators that can help in the evaluation and selection of the scenarios.

For all the main domains of investigation, a list of inputs and outputs is described as well as the methodology to derive the seconds from the firsts.

Chapter 1 recaps the scenarios (technical options) described in D2.6.

Chapter 2 recaps the interactions among the different modules of the SO WHAT tool highlighting where and how the KPIs panel intervene in the overall workflow for the evaluation procedure of different scenarios.

Chapter 3 presents the theoretical framework that undergoes the KPIs calculation specifying the different option for the end-user in both the free online and the commercial versions of the tool. The complete list of KPIs divided into four main domains is then presented.

Chapter 4 is dedicated to the definition of the algorithms that will be implemented in the SO WHAT tool for scenarios evaluation.

Chapter 5 is dedicated to the conclusions.

Abbreviations

CAPEX Capital Expenditure

CF conventional fuel

DHCN District Heating and Cooling Network

DPBP Discounted Pay Back Period

ESCO Energy Service Company

FEC Final energy consumption

GUI Graphical User Interface

IPMVP International Measurement and Verification Protocol

IRR Internal Rate of Return

KPI Key Performance Indicators

LCOEH Levelized Cost of Excess Heat

NPV Net Present Value

OPEX Operating Expenditure

PEC Primary Energy Consumption

RES Renewable Energy Sources

SCIS Smart Cities Information System

UEC Useful Energy Consumption

UI User Interface

UX User Experience

WHC Waste Heat/Cold

YEOH Yearly Equivalent Operative Hours

TABLE OF CONTENTS

1 Introduction

As reported in D2.4 "Report and presentation on SO WHAT integrated tool functionalities", the tool will be provided with a dashboard where the energetic, environmental and economic KPIs will be displayed in order to understand the performance of different scenarios.

In SO WHAT D2.6, scenarios are defined as "a potential future state" and include the technological set-up of the excess heat valorisation system. The user will be able to select from a list of set scenarios and KPIs that they are interested in. The methodology for the hierarchy of scenarios is designed in order to guide the different users to view and choose the most appropriate technologies and combinations that suit their context and requirements. Thanks to the previous experience gained in the development of Planheat Project, Remain Project and IES software, a comprehensive panel of KPIs is provided in order to support the SO WHAT end-user in the evaluation of the selected future scenarios.

First, the user must conduct a baseline simulation of the current state for the evaluation of the waste heat/cooling potential and so this is considered as the top in the hierarchy and first scenario to consider (step 1). Next step is that scenarios for reduction of energy use and elimination of waste heat/cooling are suggested, which are however not in the full scope of SO WHAT (nevertheless, the possibility to eliminate a waste, instead of recovering it, is a priority). This is followed by suggestions for internal heat/cold recovery or producing electricity for internal use (steps 3 and 4). Then, as the final steps in the hierarchy, scenarios for external delivery of excess heat/cold is suggested (step 5 and 6).

Figure 1: SO WHAT tool scenario hierarchy
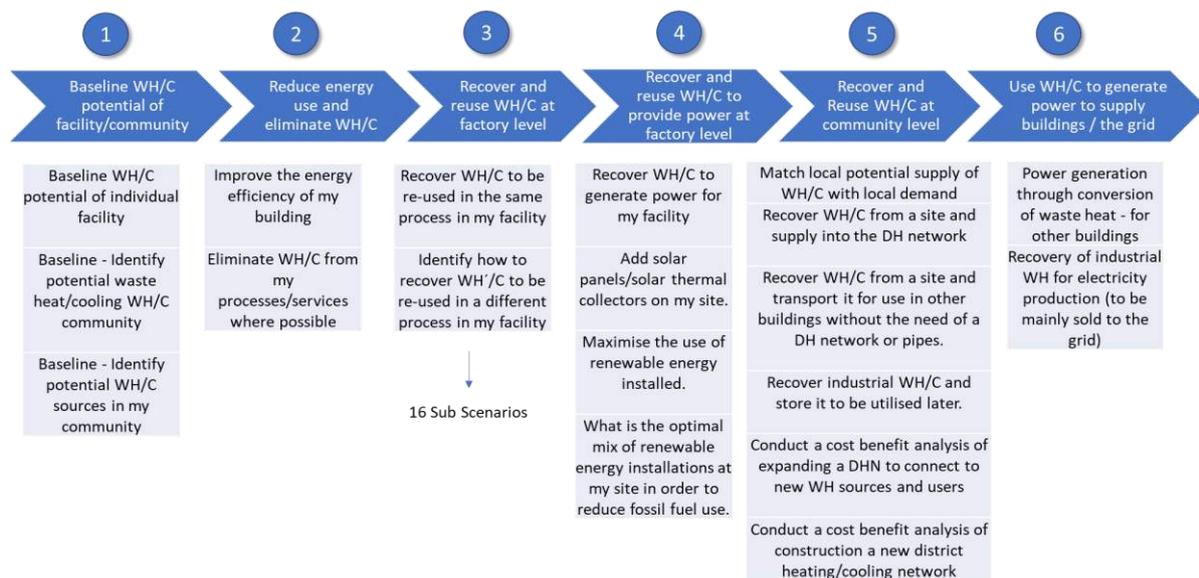
In the Decision Support Module, the assessment of the scenarios is performed via the calculation of economic, energetic and environmental KPIs that allow their evaluation.

This document is focused on the definition of the KPIs panel that will be integrated in the SO WHAT tool to evaluate scenarios and verify if they are compliant with the targets set at the beginning of the process.

2 KPIs panel interaction with SO WHAT modules

As anticipated in previously published deliverable D2.3 report on "Common IT Framework Specifications", for both the online and advanced versions of the SO WHAT tool, the so-called "KPI Panel and Dashboard" is where end users will view the results of their simulations. More precisely, the SO WHAT tool will include a KPI panel where simulation results for various scenarios of interest can be viewed, as well as a dashboard format of this KPI panel where users can visualise KPI results in an integrated manner within the 3D & 2D map view of their building/local area.

As can be seen highlighted in red in Figure 2 and Figure 3 below, the aforementioned KPI Panel is integrated within the SO WHAT online portal for both the free and commercial versions of the SO WHAT tool. In particular, it stands as one of the key functions of the SO WHAT tool Decision Support module.
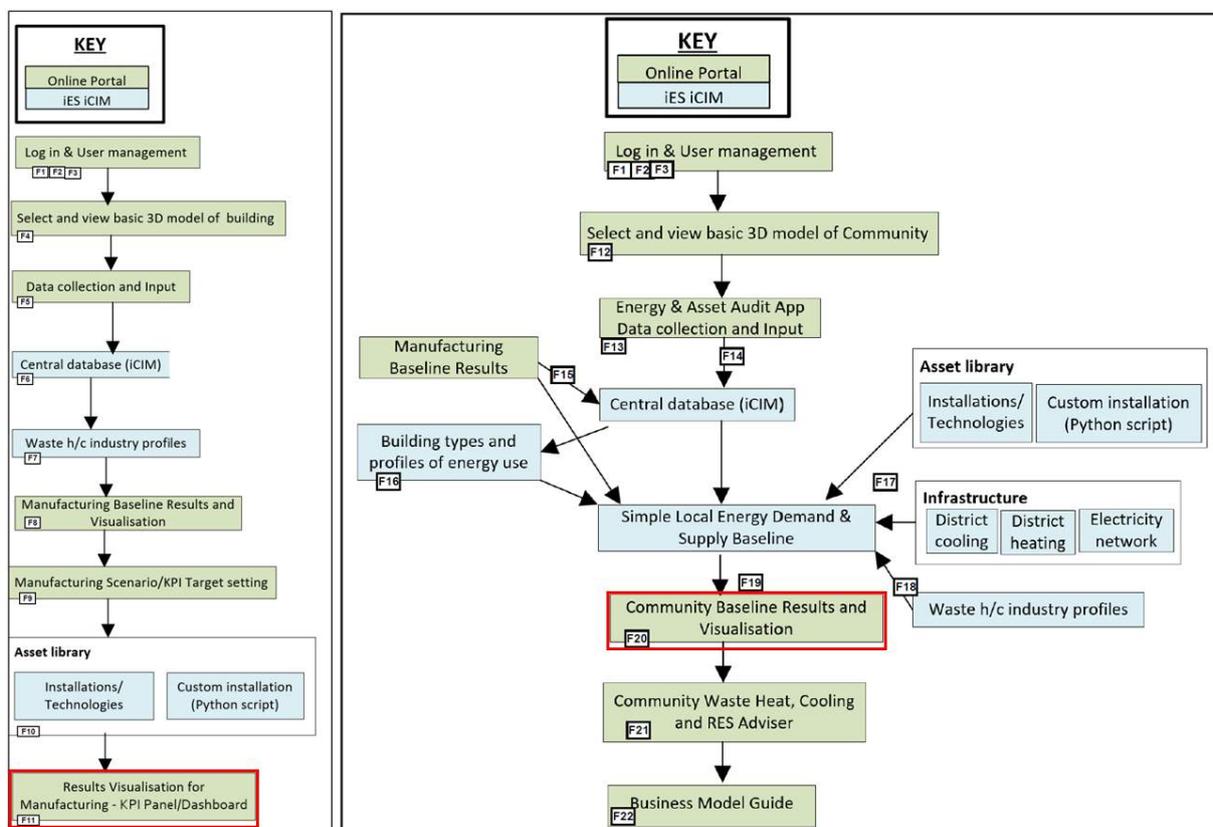
Figure 2: SO WHATonline tool Manufacturing (on the left) and Community (on the right) workflows

By considering workflows for the SO WHAT online tool, as detailed in Figure 2, the KPI panel is most relevant to use cases F11 and F20 for the manufacturing and community uses, respectively. Thus, users can view results on the potential to utilise recovered waste heat/cold within manufacturing facility (F11), or can visualise a simple baseline that shows energy consumption from local sources, as well as supply sources and constraints (F20).
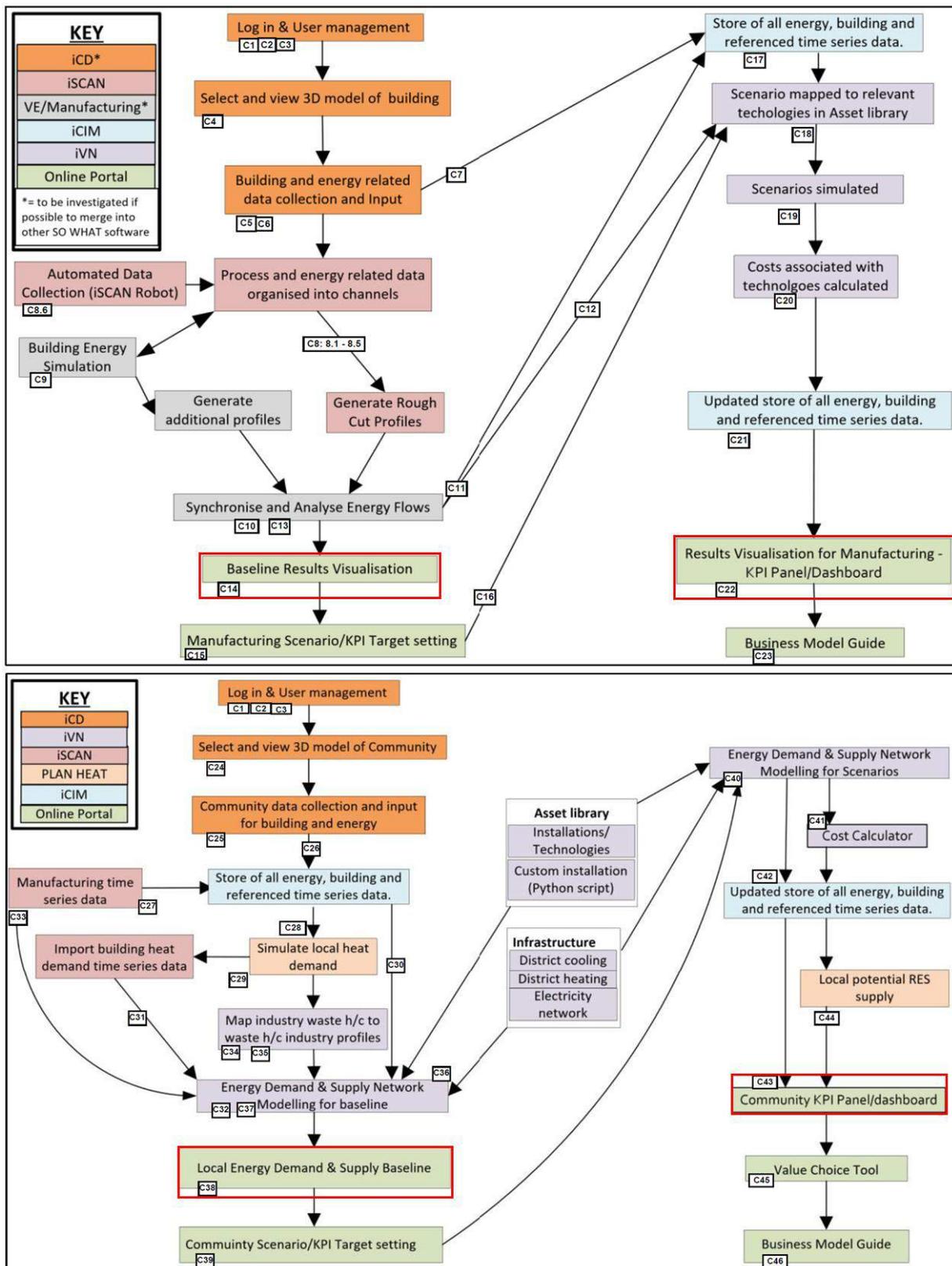
Figure 3: SO WHAT advanced tool Manufacturing (on top) and Community (at the bottom) workflows

By considering workflows for the SO WHAT advanced tool, as detailed in Figure 3, the KPI panel is most relevant to use cases C14 and C22 (manufacturing use), as well as to use cases C38 and C43 (community use). Thus, manufacturing users can view baseline results on manufacturing waste heat/cooling resource potential and on how they can recover and re-use the waste heat/cooling within their own facility for a selected set of scenarios of interest (C14 and C22). Also, community users can view community baseline results, which show the dynamic local energy consumption and supply network, including where waste heat/cooling is generated, as well as the simulation results for a selected set of scenarios (C38 and C43).

Additionally, overall, it should be noted that a particular KPI might be calculated through the online version of the SO WHAT tool in a different way than through the advanced one. This is due, for example, to different quantity and quality of data that will be requested to the SO WHAT tool users in the two versions, thus leading a simplified KPI calculation through the online version when compared to the advanced version.

Similarly, a particular KPI might be visualised, through both the versions of the SO WHAT tool, in a different way from one tool user to another, depending on the most relevant format, resolution and scale for each user category, as further detailed in following Section 3. For example, a specific KPI could be visualised on different time scales to the various users (e.g. average values over the year or continuous).

3 KPIs panel to evaluate future scenarios

Key performance indicators (KPIs) are crucial to determine the performance of a system and to evaluate it against other similar systems and with respect to a reference "baseline" configuration.

As a basis for the definition of the KPIs algorithms, the International Performance Measurement and Verification Protocol (IPMVP)[2] and the technical documentation of Concerto initiative in the framework of the Smart Cities Information System (SCIS)[3], have been considered. Due to the peculiarity of the type of investigation and the complexity of the system considered, the cited protocols and algorithms have been adapted and customized as described in the following sections.

KPIs are intended both to evaluate the variations between baseline reference scenarios and future scenarios generated by the SO WHAT tool according to selected general criteria and to benchmark future scenarios evaluating their performance.

According to the information presented in D2.4, both in the Online Free tool and in the Advanced Commercial tool versions of the SO WHAT tool, depending from the selected scenario, a list of KPI will be presented to the end-user for the assessment of the baseline reference scenario first and of the future scenarios afterwards. In the middle it will be possible to set target for each selected KPI.

According to the type of preliminary defined scenarios selected by the end-user, the same KPI can be considered following the perspective of three main stakeholders that can be identified as the main users of the SO WHAT tool: the **industrial facility** that recovers excess heat and/or cool from its processes and wants to exploit it, the **surrounding community** (also identified as a variegated group of stakeholders such as **Municipality / Regional Energy Agencies /Public Authorities)** that wants to take advantage from a local produced source of heat and the **district heating/cooling network operator**, a third stakeholder (often represented by an ESCO) that can intervene not only to facilitate the activities related to heat recovery and heat utilization by introducing capitals and by providing services, but often by owning and managing the "grey area" between the point of production to the point of delivery.
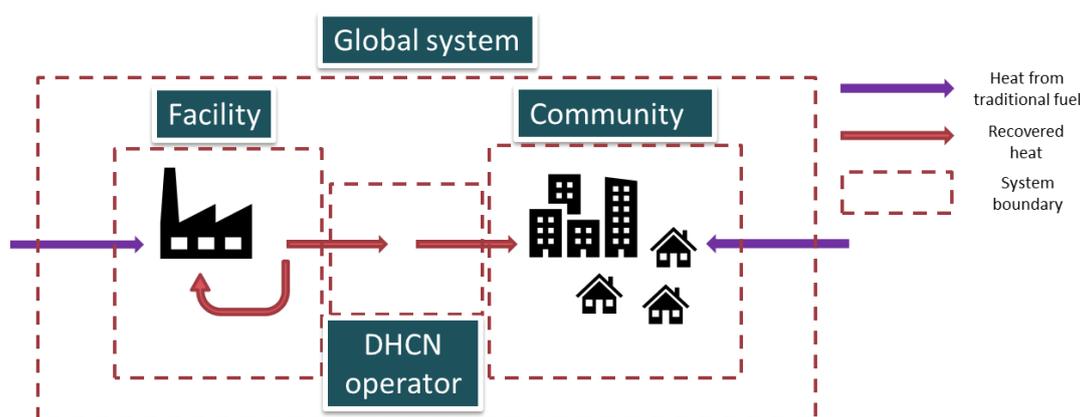

Figure 4: System boundaries for KPIs calculation

The SO WHAT tool will provide the possibility to calculate the list of KPIs selectively by the selection of the type of stakeholder considered, in particular by considering the facility form one side, the surrounding community form the other side and the DHCN operator in the middle. The possibility to calculate each indicator for the **whole scenario** is however always foreseen. As can be seen in Figure 4, three different areas have been identified corresponding to the three main perspectives for KPIs calculation. The general equations for the calculation of the KPIs further presented can be applied to each area considering the specific inputs and outputs, the energy, monetary and material flows crossing the boundaries or exchanged within the boundaries.

Four main domains have been considered for the evaluation process: energetic, environmental, economic and social since they represent the four main categories that better describe the energy and non-energy related aspects of an industrialized area connected to an urban territory and the impacts that imply the modification of the energy structure introducing the possibility to recover waste heat. Moreover, for each KPI of the four different lists is indicated in which version of the tool (free (F) or commercial (C)) can be calculated.

3.1 Economic domain

In D3.6 "Guidelines for algorithms development for economic evaluation", the economic KPIs panel has been already presented. In Table 1, the eight different economic KPIs related to four different general criteria are again presented for the sake or completeness.

Table 1 Economic KPIs panel

			KPI related			UoM	F/C
Economic	ECO1	Creation of economically feasible H&C scenarios	Discounted Payback period	ECO 1.1	DPBP	y	F/C
			Net present value	ECO 1.2	NPV	€	F/C
			Internal Rate of Return	ECO 1.3	IRR	/	F/C
			Investment cost	ECO 1.4	CAPEX	€	F/C
	ECO2	Operational costs reduction	Operational cost	ECO 2.1	OPEX	€/y	C
			Operational cost savings	ECO 2.2	OPEXsav	€/y	C
	ECO3	Levelized cost of excess heat	Achieve acceptable levelized cost of excess heat (LCOEH)	ECO 3.1	LCOEH	€/MWh	C
	ECO4	CO2 reduction cost	Cost reduction due to CO2 emission savings	ECO 4.1	CO2costred	€/tCO2/y	F/C

ECO1 KPIs are related to "Creation of economically feasible heating and cooling scenarios" criterion. Four main KPIs are included to evaluate the economic feasibility of future scenarios: payback period, net present value, internal rate of return and total investment cost.

ECO2 KPIs are related to "Operational costs reduction" criterion. The focus is on the operational cost in terms of fuel costs and management costs associated to the technologies deployed.

ECO3 KPI is related to "Achieve acceptable levelized cost of excess heat (LCOEH)" criterion. The focus is to calculate the levelized cost of excess heat production based on the technologies applied in future scenarios.

ECO4 KPI is related to "Cost reduction due to CO_2 emission savings" criterion and calculates the cost of one ton of CO_2 saved in future scenarios with respect to the baseline scenario emissions.

3.2 Energetic domain

The Energetic domain takes into consideration parameters related to final, primary and useful energy demands and consumptions; absolute variations with respect the values of the assessed baseline scenario are considered and savings are also calculated (Table 2).

Table 2 Energetic KPIs panel

			KPI related			UoM	F/C
Energetic	EN1	**Reduction of primary energy consumption**	Primary energy consumption baseline	EN 1.1	PECbase	MWh/time	F/C
			Specific primary energy consumption baseline	EN 1.2	sPECbase	MWh/m2/time	F/C
			Primary energy consumption future	EN 1.3	PECfut	MWh/time	F/C
			Specific primary energy consumption future	EN 1.4	sPECfut	MWh/m2/time	F/C
			Primary energy consumption variation from baseline	EN 1.5	PECvar	%	F/C
			Primary energy savings	EN 1.6	PECsav	MWh	F/C
	EN2	**Reduction of final energy consumption**	Final energy consumption baseline	EN 2.1	FECbase	MWh/time	F/C
			Specific final energy consumption baseline	EN 2.2	sFECbase	MWh/m2/time	F/C
			Final energy consumption future	EN 2.3	FECfut	MWh/time	F/C
			Specific final energy consumption future	EN 2.4	sFECfut	MWh/m2/time	F/C
			Final energy consumption variation from baseline	EN 2.5	FECvar	%	F/C
			Final energy savings	EN 2.6	FECsav	MWh	F/C
	EN3	**Reduction of useful energy consumption**	Useful energy consumption baseline	EN 3.1	UECbase	MWh/time	C
			Specific useful energy consumption baseline	EN 3.2	sUECbase	MWh/m2/time	C
			Useful energy consumption future	EN 3.3	UECfut	MWh/y	C
			Specific useful energy consumption future	EN 3.4	sUECfut	MWh/m2/time	C
			Useful energy consumption	EN 3.5	UECvar	%	C

Horizon 2020
European Union Funding
for Research & Innovation

		variation from baseline				
EN4	**Increase share of renewable energy sources**	Primary energy consumption from RES baseline	EN 4.1	RESbase	MWh/time	F/C
		RES penetration baseline	EN 4.2	RESbase%	%	F/C
		Primary energy consumption from RES future	EN 4.3	RESfut	MWh/time	C
		RES % future	EN 4.4	RESfut%	%	C
		RES variation from baseline	EN 4.5	RESvar	%	C
EN5	**Increase utilization of energy from waste heat/cold sources**	Energy consumption from WHC baseline	EN 5.1	WHCbase	MWh/time	F/C
		WHC % baseline	EN 5.2	WHCbase%	%	F/C
		Energy consumption from WHC future	EN 5.3	WHCfut	MWh/time	F/C
		WHC % future	EN 5.4	WHCfut%	%	F/C
		WHC variation from baseline	EN 5.5	WHCvar	%	F/C
EN6	**Reduction of energy consumption from conventional fuels**	Primary energy consumption from Conventional Fuels baseline	EN 6.1	CFbase	MWh/time	F/C
		CFs % baseline	EN 6.2	CFbase%	%	F/C
		Primary energy consumption from CFs future	EN 6.3	CFfut	MWh/time	F/C
		CFs % future	EN 6.4	CFfut%	%	F/C
		CFs variation from baseline	EN 6.5	CFvar	%	F/C
EN7	**Use of local sources**	Primary energy consumption from local sources baseline	EN 7.1	locsourbase	MWh/time	C
		Local sources % baseline	EN 7.2	locsourbase%	%	C
		Primary energy consumption from local sources future	EN 7.3	locsourfut	MWh/time	C
		Local sources % future	EN7.4	locsourfut%	%	C
		Local sources variation from baseline	EN 7.5	locsourvar	%	C
EN8	**DHCN penetration**	Baseline share of DHCN in the total	EN 8.1	DHCNbase	%	C

		useful energy consumption				
		Future share of DHCN in the total useful energy consumption	EN 8.2	DHCNfut	%	C
		Increased share of DHCN in the total useful energy consumption	EN 8.3	DHCNvar	%	C
EN9	DHN thermal losses reduction	DHCN thermal losses baseline	EN 9.1	DHNlossbase	MWh/time	C
		DHCN thermal losses future	EN 9.2	DHNlossfut	MWh/time	C
		DHCN thermal losses variation from baseline scenario	EN 9.3	DHNlossvar	MWh/time	C
EN10	DHN heat density reduction	DHCN linear heat density baseline	EN 10.1	DHNlhdbase	MWh/m/time	C
		DHCN linear heat density future	EN 10.2	DHNlhdfut	MWh/m/time	C
		DHCN linear heat density variation from baseline scenario	EN 10.3	DHNlhdvar	MWh/m/time	C
EN11	Operating hours increase	Yearly Equivalent Operating Hours baseline	EN 11.1	YEOHbase	h/y	C
		Yearly Equivalent Operating Hours future	EN 11.2	YEOHfut	h/y	C
		Yearly Equivalent Operating Hours variation	EN 11.3	YEOHvar	h/y	C

The KPIs of the energetic domain are divided in eleven main groups corresponding to related overall criteria. A detailed description is provided in section 4 together with the definition of the algorithms.

EN1 KPIs are related to "Reduction of primary energy consumption" criterion; the focus is to assess the different scenario whether they are baseline or future in terms of primary energy consumption.

EN2 KPIs are related to "Reduction of final energy consumption" criterion. According to SO WHAT approach, final energy is considered the energy contained in each source (natural gas, electricity, biomass, etc.) and used to cover the demand of heat and cool at building or industrial facility level and is calculated per each source separately. As per EN1, variation from baseline reference scenario and related savings are also calculated.

EN3 KPIs are related to "Reduction of useful energy consumption" criterion. According to SO WHAT approach, useful energy is considered the energy consumed at building or facility level to maintain the desired temperature levels. Between the final and the useful energy consumption the efficiency of the conversion, transmission and emission systems is considered.

EN4 to EN7 KPIs are related respectively to the calculation of energy consumption from renewables, waste heat sources, conventional (fossil) fuels and local sources. From a general point of view, local sources are considered the sources that can be harvested form power plants in the close proximity of the area under investigation such as solar power, wind power, biomass, geothermal power that usually are renewable sources as well. Introducing the category "renewable sources" the intention is to consider the use of renewables also in case they are not produced in close proximity. Variation and savings from baseline reference values are calculated.

EN8 KPIs are related to "DHCN penetration" criterion. This indicator evaluates the rate of penetration of heating and cooling networks in the baseline and future scenarios considering how much of the useful energy consumption is related to such systems.

EN9 KPIs are related to "DHCN thermal losses reduction" criterion. This indicator is directly related to the final energy consumption of the district heating or cooling networks present and foreseen in the baseline and future scenarios and to the thermal efficiency of the pipes distributing hot or cold water to the end-users.

EN10 KPIs are related to "DHCN heat density reduction" criterion and evaluating the transmission losses related to the length of the network that provides the hot or cold water to the end-user.

Finally, EN11 KPIs are related to "Operating hours reduction" planning criterion. For this KPIs the information regarding the capacity installed per each of the sources considered is needed thus it is not applicable to the City Planning Module but to the District Planning Module where this information is available.

3.3 Environmental domain

The KPIs of the environmental domain are divided in three main groups corresponding to related general criteria (Table 3).

A detailed description is provided in section 4 together with the definition of the algorithms.

Table 3 Environmental KPIs panel

			KPI related			UoM	F/C
Environmental	ENV1	CO2 reduction	CO_2 emission baseline	ENV 1.1	CO2base	tCO_2	F/C
			specific CO_2 emission baseline	ENV 1.2	sCO2base	tCO_2/m^2	F/C
			CO_2 emission future	ENV 1.3	CO2fut	tCO_2	F/C
			specific CO_2 emission future	ENV 1.4	sCO2fut	tCO_2/m^2	F/C
			CO_2 emission variation from baseline	ENV 1.5	CO2var	%	F/C
			CO_2 emission savings	ENV 1.6	CO2sav	tCO_2	F/C
	ENV2	SOx reduction	SOx emission baseline	ENV 2.1	SOxbase	tSOx	C?
			specific SOx emission baseline	ENV 2.2	sSOxbase	$tSOx/m^2$	C?
			SOx emission future	ENV 2.3	SOxfut	tSOx	C?
			specific SOx emission future	ENV 2.4	sSOxfut	$tSOx/m^2$	C?

		SOx emission variation from baseline	ENV 2.5	SOxvar	%	C?
		SOx emission savings	ENV 2.6	SOx sav	tSOx	C?
ENV3	NOx reduction	NOx emission baseline	ENV 3.1	NOxbase	tNOx	C?
		specific NOx emission baseline	ENV 3.2	sNOxbase	$tNOx/m^2$	C?
		NOx emission future	ENV 3.3	NOxfut	tNOx	C?
		specific NOx emission future	ENV 3.4	sNOxfut	$tNOx/m^2$	C?
		NOx emission variation from baseline	ENV 3.5	NOxvar	%	C?
		NOx emission savings	ENV 3.6	NOx sav	tNOx	C?
ENV4	PM10 reduction	PM10 emission baseline	ENV 4.1	PM10base	tPM10	C?
		specific PM10 emission baseline	ENV 4.2	sPM10base	$tPM10/m^2$	C?
		PM10 emission future	ENV 4.3	PM10fut	tPM10	C?
		specific PM10 emission future	ENV 4.4	sPM10fut	$tPM10/m^2$	C?
		PM10 emission variation from baseline	ENV 4.5	PM10var	%	C?
		PM10 emission savings	ENV 4.6	PM10sav	tPM10	C?
ENV5	Noise pollution reduction	Noise pollution variation from baseline	ENV 5.1	dBpollvar	%	C?

Please note that in the above Table, "C?" means that data required (e.g. emission factors specific to each fuel type and for different pollutants) for the calculation of these KPIs should already be available from PlanHeat tool, and thus should be integrated within the Commercial version of the SO WHAT tool. However, such a granular breakdown of emissions into different pollutants, rather than an estimation of overall carbon-equivalent CO_2 emissions, is not currently a requirement for the SO WHAT tool. Therefore, should this optional feature become a requirement, as based on the outcomes from WP5 tool testing activities, additional development needs and resources required to integrate this optional feature into the Commercial version of the SO WHAT tool will be evaluated and considered.

ENV1 KPIs are related to "CO_2 reduction" general criterion. Variation and saving form the baseline scenarios values are calculated; CO_2 emission factor are needed and in case not available can be retrieved as default values from SO WHAT "Central database".

As for ENV1 KPIs, ENV2, ENV3 and ENV4 are related to "Pollutant emission reduction" general criteria. For each considered source, the emissions of NO_x, SO_x and PM10 are evaluated both in the baseline reference scenario and in future scenarios and function of the related primary energy consumptions. Pollutant emission factors are available as default values in SO WHAT "Central database".

ENV3 KPIs are related to "noise pollution reduction" general criterion. The variation between the baseline reference scenario and future scenarios is evaluated.

3.4 Social domain

The KPIs of the social domain are divided in three main groups corresponding to related general criteria (Table 4).

A detailed description is provided in section 4 together with the definition of the algorithms.

Table 4 Social KPIs panel

			KPI related			UoM	F/C
Social	SO1	Energy poverty reduction	Energy poverty baseline	SO 1.1	Enpovbase	€/time/m²	C?
			Energy poverty future	SO 1.2	Enpovfut	€/time/m²	C?
			Energy poverty variation from baseline	SO 1.3	Enpovvar	%	C?
	SO2	Security of supply	security of supply baseline	SO 2.1	ssbase	%	C?
			security of supply future	SO 2.2	ssfut	%	C?
			security of supply variation from baseline	SO 2.3	ssvar	%	C?
	SO3	Job increase	Job variation from baseline	SO 3.1	Jobin	%	C?

Please note that in the above Table, "C?" means there is a high level of uncertainty with regards a consistent definition for these KPIs across different users, as well as in relation to the accessibility and quality for the data required to calculate these KPIs.

SO1 KPI is related to "Energy poverty reduction" criterion and compares the expenses due to energy consumption to the profits of the inhabitants and activities in the area under investigation.

SO2 KPI is related to "security of supply" criterion and calculates the rate of utilization of local sources with respect their availability in the surrounding area.

SO3 KPI is related to "Job increase" criterion and calculates the job increase due to the new investments enabled by the changes needed to improve the energetic system from baseline to future scenarios.

4 KPI calculation algorithms

SO WHAT tool KPIs are intended to provide information at three different levels: the first level is to give a quantitative evaluation of the created future scenario performance, the second level is to compare future scenarios among them to determine which one represents the best scenario according to criteria selected, the third level is related to the calculation of cost, energetic and environmental savings with respect the values coming from the assessed baseline reference scenario. With respect the third level of information, the IPMVP protocol is taken as reference for saving calculation.

As represented in Figure 5, the approach to evaluate the energy (and related cost and environmental) savings is done considering the adjusted baseline profile to compare the values of the future scenarios to the baseline reference scenario. In fact, some independent variables that affects the energy consumption (throughput increase, population increase, increase of DHCN extension, etc.) can vary from the reference period to the period after the implementation of energy savings measures; in this case the values of the baseline scenarios have to be adjusted accordingly.
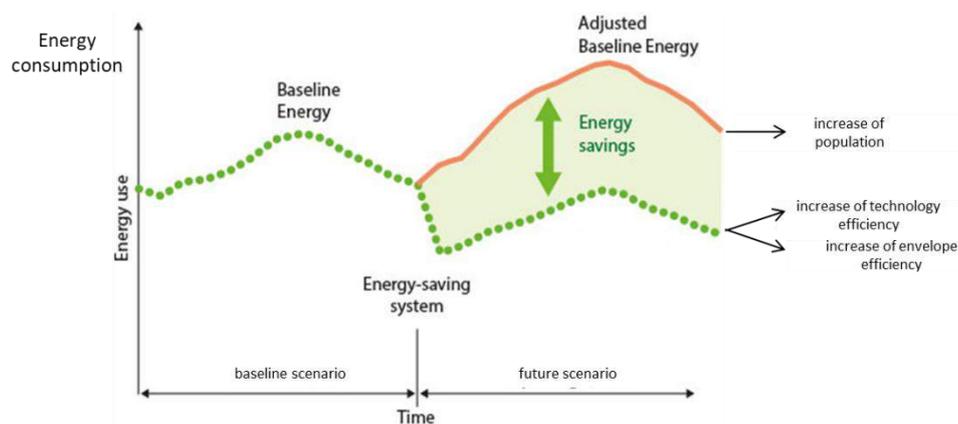

Figure 5 IPMVP approach for energy savings calculation

Moving from baseline current scenario to future scenarios, what is considered in SO WHAT tool affecting the energy (and related parameters) consumptions are the increase of technology efficiency and increase of the efficiency of the building performance in terms of energy request to maintain the desired comfort levels.

In the description of the algorithms the mechanism of the adjustment of the baseline values will be explained in detail.

4.1 Energetic domain

4.1.1 Primary energy consumption baseline (EN 1.1 PECbase)

The total primary energy consumption of the baseline scenario is calculated as the sum of the primary energy consumptions related to all the sources employed in the system. The primary energy consumption of each source is calculated as the product of the final energy consumption and the related primary energy factor. The equations for the calculation can be applied to each of the four areas in which the system has been divided: facility, community, DHCN operator, global system.

$$PECbase_{tot}[\text{MWh/time}] = \sum_s PECbase_s \ (1)$$

$$PECbase_s[\text{MWh/time}] = FECbase_s \times primary\ energy\ factor_s \ (2)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *primary energy factor* represents an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.1.2 Specific primary energy consumption baseline (EN 1.2 sPECbase)

According to (1) the specific primary energy consumption is calculated in (3).

$$sPECbase_{tot}[\text{MWh/time/m}^2] = \frac{PECbase_{tot}}{m^2} \ (3)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.1.3 Primary energy consumption future (EN 1.3 PECfut)

As per the reference baseline scenario, the total and per source primary energy consumption of future scenario is calculated in (4) and (5).

$$PECfut_{tot}[\text{MWh/time}] = \sum_s PECfut_s \ (4)$$

$$PECfut_s[\text{MWh/time}] = FECfut_s \times primary\ energy\ factor_s \ (5)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *primary energy factor* represents an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.1.4 Specific primary energy consumption future scenario (EN 1.4 sPECfut)

According to (5) the specific primary energy consumption is calculated in (6).

$$sPECfut_{tot}[\text{MWh/time/m}^2] = \frac{PECfut_{tot}}{m^2} \ (6)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of approach used

4.1.5 Primary energy consumption variation from baseline (EN 1.5 PECvar)

The primary energy consumption variation from baseline represents the variation in percentage of the total primary energy consumption from baseline to future scenario.

$$PECvar_{tot}[\%] = \left[\frac{PECfut_{tot}}{PECbase_{tot}} - 1\right] \times 100 \ (7)$$

4.1.6 Primary energy consumption saving (EN 1.6 PECsav)

The primary energy consumption saving is calculated as the difference between the future scenario and the baseline scenario values. According to the specific case, the baseline value could be adjusted to consider specific events that interested the system during the deployment of the energy conservation measures such as increased number of building, increased population or increased production of the facility according to the directive of the IPMVP protocol.

$$PECsav_{tot}[MWh/time] = PECbase_{tot} - PECbase_{fut} \ (8)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.1.7 Final energy consumption baseline (EN 2.1 FECbase)

The final energy consumption of the baseline scenario is referred to each source considered within the boundaries of the system under investigation. This indicator can be an input to the SO WHAT tool in case historical or measured data are available or can be calculated by the tool in case both the energy provided and the performance of the equipment used to provide energy are instead available. To exemplify, from the *industrial facility* point of view, some waste heat recovered internally could be used to provide space heating thus replacing the usual system and therefore avoiding the consumption of some fuel (natural gas, biomass, heating oil, etc.). It is important then to quantify the amount of final energy corresponding to the amount of energy that has been substituted after the application of the energy conservation measure. Form the *community* point of view, it is important to understand the final energy consumption of the baseline scenario that will be replaced (in total or in part) thanks to heat recovered and distributed by the industrial facility in the close proximity. In case the final energy consumption is not directly coming from historical or measured data but need to be calculated from measured data of consumed heat or calculated heat demand, the equation (9) will be used.

$$FECbase_s[MWh/time] = \frac{UECbase}{\eta_g} \ (9)$$

Where

- *time* represents the resolution of the reference period of calculation
- *UECbase* represents the measured or calculated useful energy consumption in the baseline scenario
- η_g represents the global efficiency of conversion/transmission/emission from the point of generation to the point of consumption

Alternatively, in case the useful energy demand has been provided by more than one production system, the equation (10) will be considered

$$FECbase_s[MWh/time] = (AvCap_{tech} \times OHbase)/\eta_{tech} \ (10)$$

Where

- *time* represents the resolution of the reference period of calculation

- η_{tech} represents the efficiency of conversion of the specific technology
- $AvCap_{tech}$ represents the average capacity of the generation asset in terms of available power in the time frame considered in [MW]
- $OHbase$ represents the operative hours of the generation asset in the time frame considered

4.1.8 Specific final energy consumption baseline (EN 2.2 sFECbase)

According to (9) or (10), the specific baseline final energy consumption for each source considered in the system(s) can be calculated with (11).

$$sFECbase_s[\text{MWh/time/m}^2] = \frac{FECbase_s}{m^2} \ (11)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.1.9 Final energy consumption future (EN 2.3 FECfut)

As per the reference baseline scenario, the final energy consumption per each source considered in future scenario is calculated in (12) or (13).

$$FECfut_s[\text{MWh/time}] = \frac{UECfut}{\eta_g} \ (12)$$

Where

- *time* represents the resolution of the reference period of calculation
- *UECfut* represents the measured or calculated useful energy consumption in the future scenario
- η_g represents the global efficiency of conversion/transmission/emission from the point of generation to the point of consumption

$$FECfut_s[\text{MWh/time}] = (AvCap_{tech} \times OHfut)/\eta_{tech} \ (13)$$

Where

- *time* represents the resolution of the reference period of calculation
- η_{tech} represents the efficiency of conversion of the specific technology
- $AvCap_{tech}$ represents the average capacity of the generation asset in the time frame considered in [MW]
- $OHfut$ represents the operative hours of the generation asset in the time frame considered

4.1.10 Specific final energy consumption future (EN 2.4 sFECfut)

According to (12) or (13), the specific future final energy consumption for each source considered in the system(s) can be calculated with (14).

$$sFECfut_s[\text{MWh/time/m}^2] = \frac{FECfut_s}{m^2} \ (14)$$

Where:

- *time* represents the resolution of the reference period of calculation

- m^2 being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.1.11 Final energy consumption variation (EN 2.5 FECvar)

The final energy consumption variation from baseline represents for each source the variation in percentage of the final energy consumption from baseline to future scenario. According to the specific case, the baseline value could be adjusted to consider specific events that interested the system during the deployment of the energy conservation measures such as increased number of building, increased population or increased production of the facility according to the directive of the IPMVP protocol.

$$FECvar_s[\%] = \left[\frac{FECfut_s}{FECbase_s} - 1\right] \times 100 \ (15)$$

4.1.12 Final energy consumption savings (EN 2.6 FECsav)

The final energy consumption saving is calculated per each source as the difference between the future scenario and the baseline scenario values. According to the specific case, the baseline value could be adjusted to consider specific events that interested the system during the deployment of the energy conservation measures such as increased number of building, increased population or increased production of the facility according to the directive of the IPMVP protocol.

$$FECsav_s[MWh/time] = FECbase_s - PECbase_s \ (16)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.1.13 Useful energy consumption baseline (EN 3.1 UECbase)

The useful energy consumption of the baseline reference scenario represents the energy that needs to be provided to cover the demand for space heating, space cooling, domestic hot water preparation, specific industrial processes. Depending on the data available, on the specific application and on the specific area of investigation the useful energy consumption can be: acquired as an input, calculated from the final energy consumption, calculated from another SO WHAT module by considering the envelop characteristics of a building and/or the characteristics of an industrial process. In the second case, the equation used to calculate the indicator is reported in (17).

$$UECbase_{tot}[MWh/time] = \sum_s(FECbase_s \times \eta_g) \ (17)$$

Where:

- *time* represents the resolution of the reference period of calculation
- η_g represents the global efficiency of conversion/transmission/emission from the point of generation to the point of consumption
- $FECbase_s$ represents the final energy consumption of each source in the baseline scenario

4.1.14 Specific useful energy consumption baseline (EN 3.2 sUECbase)

According to (17) the specific useful energy consumption in the baseline scenario is calculated as reported in (18) and referred to the total surface of the building(s) considered.

$$sUECbase_{tot}[MWh/time/m^2] = \frac{UECbase_{tot}}{m^2} \ (18)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.1.15 Useful energy consumption future (EN 3.3 UECfut)

As per the reference baseline scenario, the total useful energy consumption can be calculated as reported in (19).

$$UECfut_{tot}[\text{MWh/time}] = \sum_s (FECfut_s \times \eta_g) \text{ (19)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- η_g represents the global efficiency of conversion/transmission/emission from the point of generation to the point of consumption
- $FECfut_s$ represents the final energy consumption of each source in the future scenario

4.1.16 Specific useful energy consumption future (EN 3.4 sUECfut)

According to (19) the specific useful energy consumption in the future scenario is calculated as reported in (20) and referred to the total surface of the building(s) considered.

$$sUECfut_{tot}[\text{MWh/time/m}^2] = \frac{UECfut_{tot}}{m^2} \text{ (20)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.1.17 Useful energy consumption variation (EN 3.5 UECvar)

The useful energy consumption variation from baseline represents the variation in percentage of the useful energy demand from baseline to future scenario.

$$UECvar_{tot}[\%] = \left[\frac{UECfut_{tot}}{UECbase_{tot}} - 1\right] \times 100 \text{ (21)}$$

4.1.18 Primary energy consumption from RES baseline (EN 4.1 RESbase)

The total primary energy consumption from renewables in the baseline reference scenario is calculated as the sum of the primary energy consumption from each renewable source considered in the area under investigation.

$$RESbase_{tot}[\text{MWh/time}] = \sum_{res} PECbase_{res} \text{ (22)}$$

Where:

- *time* represents the resolution of the reference period of calculation

4.1.19 RES % baseline (EN 4.2 RESbase%)

According to (22) and with the total amount of primary energy consumption in baseline scenario (1), the total penetration of renewable energy sources (23) in the baseline scenario is calculated.

$$RESbase\%_{tot}[\%] = \frac{RESbase_{tot}}{PECbase_{tot}} * 100 \ (23)$$

4.1.20 Primary energy consumption from RES future (EN 4.3 RESfut)

The total primary energy consumption from renewables in the future scenario is calculated as the sum of the primary energy consumption from each renewable source considered in the area under investigation.

$$RESfut_{tot}[\text{MWh/time}] = \sum_{res} PECfut_{res} \ (24)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.1.21 RES % future (EN 4.4 RESfut%)

According to (24) and with the total amount of primary energy consumption in future scenario (4), the total penetration of renewable energy sources (26) in the future scenario is calculated.

$$RESfut\%_{tot}[\%] = \frac{RESfut_{tot}}{PECfut_{tot}} * 100 \ (25)$$

4.1.22 RES variation from baseline (EN 4.5 RESvar)

The primary energy consumption from renewables variation from baseline represents the variation in percentage of the primary energy consumption from baseline to future scenario.

$$RESvar_{tot} [\%] = \left(\frac{RESfut_{tot}}{RESbase_{tot}} - 1 \right) * 100 \ (26)$$

4.1.23 Energy consumption from waste heat/cold baseline (EN 5.1 WHCbase)

The total final energy consumption from waste heat or cold in the baseline reference scenario is calculated as the final energy consumption from each waste heat source considered in the area under investigation. The final energy from waste heat is considered as the thermal energy contained in the hot medium (water, air, steam, etc.) before the exchange with the end-user circuit (via heat exchanger, HRSG, economizer, etc.).

$$WHCbase_{tot}[\text{MWh/time}] = \sum_{WHC} FECbase_{WHC} \ (27)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $FECbase_{WH}C$ represents the final energy consumption coming from waste heat or cold sources in the baseline reference scenario

4.1.24 Waste heat/cold % baseline (EN 5.2 WHCbase%)

According to (27) and with the total amount of final energy consumption in baseline scenario, the total penetration of waste heat or cold (28) in the baseline scenario is calculated.

$$WHCbase\%_{tot}[\%] = \frac{WHCbase_{tot}}{\sum_s FECbase_s} * 100 \ (28)$$

4.1.25 Energy consumption from waste heat/cold future (EN 5.3 WHCfut)

As per the baseline reference scenario, the (final) energy consumption from waste heat or cold in future scenario is calculated with (29).

$$WHCfut_{tot}[\text{MWh/time}] = \sum_{WHC} FECfut_{WHC} \text{ (29)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- $FECfut_{WHC}$ represents the final energy consumption coming from waste heat sources in the future scenario

4.1.26 Waste heat/cold % future (EN 5.4 WHCfut%)

According to (29) and with the total amount of final energy consumption in future scenario, the total penetration of waste heat or cold (30) in the future scenario is calculated.

$$WHCfut\%_{tot}[\%] = \frac{WHCfut_{tot}}{\sum_{s} FECfut_{s}} * 100 \text{ (30)}$$

4.1.27 Waste heat/cold variation from baseline (EN 5.5 WHCvar)

The waste heat variation from baseline represents the variation in percentage of the final energy consumption from waste heat or cold from baseline to future scenario.

$$WHCvar_{tot} [\%] = \left(\frac{WHCfut_{tot}}{WHCbase_{tot}} - 1\right) * 100 \text{ (31)}$$

4.1.28 Primary energy consumption from conventional fuels baseline (EN 6.1 CFbase)

The total primary energy consumption from conventional (fossil) fuels in the baseline reference scenario is calculated as the primary energy consumption from each conventional source considered in the area under investigation.

$$CFbase_{tot}[\text{MWh/time}] = \sum_{CF} PECbase_{CF} \text{ (32)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- $PECbase_{CF}$ represents the primary energy consumption coming from conventional sources in the baseline reference scenario

4.1.29 Conventional fuels % baseline (EN 6.2 CFbase%)

According to (32) and with the total amount of primary energy consumption in baseline scenario (1), the total penetration of conventional fuels (33) in the baseline scenario is calculated.

$$CFbase\%_{tot}[\%] = \frac{CFbase_{tot}}{PECbase_{tot}} * 100 \text{ (33)}$$

4.1.30 Primary energy consumption from conventional fuels future (EN 6.3 CFfut)

The total primary energy consumption from conventional fuels in the future scenario is calculated as the sum of the primary energy consumption from each conventional fuel considered in the area under investigation.

$$CFfut_{tot}[\text{MWh/time}] = \sum_{CF} PECfut_{CF} \ (34)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $PECfut_{CF}$ represents the primary energy consumption coming from conventional sources in the future scenario

4.1.31 Conventional fuels % future (EN 6.4 CFfut%)

According to (34) and with the total amount of primary energy consumption in future scenario (4), the total penetration of conventional fuels (35) in the future scenario is calculated.

$$CFfut\%_{tot}[\%] = \frac{CFfut_{tot}}{PECfut_{tot}} * 100 \ (35)$$

4.1.32 Conventional fuels variation from baseline (EN 6.5 CFvar)

The primary energy consumption from conventional (fossil) fuels variation from baseline represents the variation in percentage of the primary energy consumption from baseline to future scenario.

$$CFvar_{tot}\ [\%] = \left(\frac{CFfut_{tot}}{CFbase_{tot}} - 1\right) * 100 \ (36)$$

4.1.33 Primary energy consumption from local sources baseline (EN 7.1 locsourbase)

The total primary energy consumption from local sources in the baseline reference scenario is calculated as the primary energy consumption from each local source considered in the area under investigation.

$$locsourbase_{tot}[\text{MWh/time}] = \sum_{ls} PECbase_{ls} \ (37)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $PECbase_{ls}$ represents the primary energy consumption coming from local sources in the baseline reference scenario

4.1.34 Local sources % baseline (EN 7.2 locsourbase%)

According to (37) and with the total amount of primary energy consumption in baseline scenario (1), the total penetration of local sources (38) in the baseline scenario is calculated.

$$locsourbase\%_{tot}[\%] = \frac{locsourbase_{tot}}{PECbase_{tot}} * 100 \ (38)$$

4.1.35 Primary energy consumption from local sources future (EN 7.3 locsourfut)

The total primary energy consumption from local sources in the future scenario is calculated as the primary energy consumption from each local source considered in the area under investigation.

$$locsourfut_{tot}[\text{MWh/time}] = \sum_{ls} PECfut_{ls} \ (39)$$

Where:

- *time* represents the resolution of the reference period of calculation

- $PECfut_{ls}$ represents the primary energy consumption coming from local sources in the future scenario

4.1.36 Local sources % future (EN 7.4 locsourfut%)

According to (39) and with the total amount of primary energy consumption in future scenario (4), the total penetration of local sources (40) in the future scenario is calculated.

$$locsourfut\%_{tot}[\%] = \frac{locsourfut_{tot}}{PECfut_{tot}} * 100 \ (40)$$

4.1.37 Local sources variation from baseline (EN 7.5 locsourvar)

The primary energy consumption from local sources variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$locsourvar_{tot}\ [\%] = \left(\frac{locsourfut_{tot}}{locsourbase_{tot}} - 1\right) * 100 \ (41)$$

4.1.38 Baseline share of DHCN in the total useful energy consumption (EN 8.1 DHCNbase)

This indicator represents the penetration of DH(C)Ns in the baseline reference scenario in terms of percentage over the total useful energy consumption i.e. how much of the thermal energy used comes from a district heating or cooling network.

$$DHCNbase\%_{tot}[\%] = \frac{UECbase_{DHCN}}{UECbase_{tot}} * 100 \ (42)$$

Where

- $UECbase_{DHCN}$ represents the amount of useful energy consumption related to district heating or cooling network in the baseline scenario

4.1.39 Future share of DHCN in the total useful energy consumption (EN 8.2 DHNCfut)

As per the baseline reference scenario, the future share of district heating or cooling networks in the total useful energy consumption is calculated with (43)

$$DHCNfut\%_{tot}[\%] = \frac{UECfut_{DHCN}}{UECfut_{tot}} * 100 \ (43)$$

Where

- $UECfut_{DHCN}$ represents the amount of useful energy consumption related to district heating or cooling network in the future scenario

4.1.40 Increased share of DHCN in the total useful energy consumption (EN 8.3 DHCNvar)

The share of DHCN in the total useful energy consumption variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$DHCNvar_{tot}\ [\%] = \left(\frac{DHCNfut_{tot}}{DHCNbase_{tot}} - 1\right) * 100 \ (44)$$

4.1.41 DHCN thermal losses baseline (EN 9.1 DHCNlossbase)

Thermal losses of district heating and cooling networks in the baseline reference scenario are calculated as the difference between the energy produced by each source used and the useful energy consumption related to district heating and cooling networks systems in the baseline scenario.

$$DHCNlossbase_{tot}[\text{MWh/time}] = \sum_s \left(FECbase_{DHCN,s} * \eta_{tech} - UECbase_{DHCN,s} \right) (45)$$

Where

- *time* represents the resolution of the reference period of calculation
- $FECbase_{DHCN,s}$ represents the final energy consumption related to each source (included waste heat) supplying the DHCN in the baseline scenario
- $UECbase_{DHCN,s}$ represents the useful energy consumption related to each source supplying the DHCN in the baseline scenario
- η_{tech} represents the efficiency of conversion of the specific technology

4.1.42 DHCN thermal losses future (EN 9.2 DHCNlossfut)

As per the reference baseline scenario, the thermal losses of district heating and cooling networks in the future scenario are calculated as the difference between the energy produced by each source used and the useful energy consumption related to district heating and cooling networks systems in future scenario.

$$DHCNlossfut_{tot}[\text{MWh/time}] = \sum_s \left(FECfut_{DHCN,s} * \eta_{tech} - UECfut_{DHCN,s} \right) (46)$$

Where

- *time* represents the resolution of the reference period of calculation
- $FECfut_{DHCN,s}$ represents the final energy consumption related to each source (included waste heat) supplying the DHCN in the future scenario
- $UECfut_{DHCN,s}$ represents the useful energy consumption related to each source supplying the DHCN in the future scenario
- η_{tech} represents the efficiency of conversion of the specific technology

4.1.43 DHCN thermal losses variation from baseline scenario (EN 9.3 DHCNlossvar)

The DHCN thermal variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$DHCNlossvar_{tot} [\%] = \left(\frac{DHCNlossfut_{tot}}{DHCNlossbase_{tot}} - 1 \right) * 100 (47)$$

4.1.44 DHCN linear heat density baseline (EN 10.1 DHCNlhdbase)

Linear heat density of district heating and cooling networks in the baseline reference scenario is calculated as the ratio between the useful energy consumption related to DHCNs and the length of the related network in the baseline scenario.

$$DHCNlhdbase_{tot} [\text{MWh/m}] = \frac{\sum_s UECbase_{DHCN,s}}{network\ lenght\ base} (48)$$

4.1.45 DHCN linear heat density future (EN 10.2 DHCNlhdfut)

As per the baseline reference scenario, the linear heat density of district heating and cooling networks in the future scenario is calculated as the ratio between the useful energy consumption related to DHCNs and the length of the related network in the future scenario.

$$DHCNlhdfut_{tot} \ [\text{MWh/m}] = \frac{\sum_s UECfut_{DHCN,s}}{network \ lenght \ fut} \ (49)$$

4.1.46 DHCN linear heat density variation from baseline (EN 10.3 DHCNlhdvar)

The DHCN linear heat density variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$DHCNlhdvar_{tot} \ [\%] = \left(\frac{DHCNlhdfut_{tot}}{DHCNlhdbase_{tot}} - 1\right) * 100 \ (50)$$

4.1.47 Yearly Equivalent Operating Hours baseline (EN 11.1 YEOHbase)

The yearly equivalent operating hours of the baseline reference scenario are calculated per each technology (equivalent to source) as the ratio between final energy consumption and installed power (51) in the baseline scenario.

$$YEOHbase_s = \frac{FECbase_s \times \eta_{tech}}{AvCap_{tech}} \ (51)$$

Where:

- $AvCap_{tech}$ represents the average capacity of the generation asset in terms of available power in the time frame considered in [MW]
- η_{tech} represents the efficiency of conversion of the specific technology

4.1.48 Yearly Equivalent Operating Hours future (EN 12.2 YEOHfut)

The yearly equivalent operating hours of the future scenario are calculated per each technology (equivalent to source) as the ratio between final energy consumption and installed power (52) in the future scenario.

$$YEOHfut_s = \frac{FECfut_s \times \eta_{tech}}{AvCap_{tech}} \ (52)$$

Where:

- $AvCap_{tech}$ represents the average capacity of the generation asset in terms of available power in the time frame considered in [MW]
- η_{tech} represents the efficiency of conversion of the specific technology

4.1.49 Yearly Equivalent Operating Hours variation from baseline (EN 12.3 YEOHvar)

According to equations (51) and (52) , the variation of the yearly equivalent operating hours are calculated following equation (53).

$$YEOHvar_s = \left(\frac{YEOHfut_s}{YEOHbase_s} - 1\right) * 100 \ (53)$$

4.2 Environmental domain

4.2.1 CO2 emission baseline (ENV 1.1 CO2base)

The total CO2 emitted by each system in the baseline reference scenario is directly correlated with the primary energy consumption through a CO2 emission factor that can be input directly by the end-user of the SO WHAT tool or retrieved as default value from a dedicated database. According to (1) and (2) the CO2 emitted can be expressed per each source considered in the system (54) or considering the total amount (55).

$$CO2base_s[\text{tCO2/time}] = PECbase_s[\text{MWh/time}] * CO2emissionfactor_s\,[\text{tCO2/MWh}]\ (54)$$

$$CO2base_{tot}[\text{tCO2/time}] = \sum_s CO2base_s\ (55)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $CO2emissionfactor_s$ represents the factor that correlates the primary energy consumption to the CO2 production in the baseline scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.2 specific CO2 emission baseline (ENV 1.2 sCO2base)

According to (55) the specific CO2 emission can be calculated in the baseline reference scenario considering (56).

$$sCO2base_{tot}[\text{tCO2/time/m}^2] = \frac{CO2base_{tot}}{m^2}\ (56)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.3 CO2 emission future (ENV 1.3 CO2fut)

As per the reference baseline scenario, the CO2 emitted in the future scenario can be calculated with (57) and (58).

$$CO2fut_s[\text{tCO2/time}] = PECfut_s[\text{MWh/time}] * CO2emissionfactor_s\,[\text{tCO2/MWh}]\ (57)$$

$$CO2fut_{tot}[\text{tCO2/time}] = \sum_s CO2fut_s\ (58)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $CO2emissionfactor_s$ represents the factor that correlates the primary energy consumption to the CO2 production in the future scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.4 specific CO2 emission future (ENV 1.4 sCO2fut)

According to (58) the specific CO2 emission can be calculated in the future scenario considering (59).

$$sCO2fut_{tot}[tCO2/time/m^2] = \frac{CO2fut_{tot}}{m^2} \quad (59)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.5 CO2 emission variation from baseline (ENV 1.5 CO2var)

The CO2 emission variation from baseline represents the variation in percentage of the total CO2 emitted from baseline to future scenario.

$$CO2var_{tot}[\%] = \left[\frac{CO2fut_{tot}}{CO2base_{tot}} - 1\right] \times 100 \quad (60)$$

4.2.6 CO2 emission savings (ENV 1.6 CO2sav)

The CO2 emission saving is calculated as the difference between the future scenario and the baseline scenario values.

$$CO2sav_{tot}[MWh/time] = CO2base_{tot} - CO2base_{fut} \quad (61)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.2.7 SOx emission baseline (ENV 2.1 SOxbase)

The total SOx emitted by each system in the baseline reference scenario is directly correlated with the primary energy consumption through a SOx emission factor that can be input directly by the end-user of the SO WHAT tool or retrieved as default value from a dedicated database. According to (1) and (2) the SOx emitted can be expressed per each source considered in the system (62) or considering the total amount (63).

$$SOxbase_s[tSOx/time] = PECbase_s[MWh/time] * SOxemissionfactor_s[tSOx/MWh] \quad (62)$$

$$SO2base_{tot}[tSOx/time] = \sum_s SOxbase_s \quad (63)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $SOxemissionfactor_s$ represents the factor that correlates the primary energy consumption to the SOx production in the baseline scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.8 specific SOx emission baseline (ENV 2.2 sSOxbase)

According to (63) the specific SOx emission can be calculated in the baseline reference scenario considering (64).

$$sSOxbase_{tot}[tSOx/time/m^2] = \frac{SOxbase_{tot}}{m^2} \quad (64)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.9 SOx emission future (ENV 2.3 SOxfut)

As per the reference baseline scenario, the SOx emitted in the future scenario can be calculated with (65) and (66).

$$SOxfut_s[\text{tSOx/time}] = PECfut_s[\text{MWh/time}] * SOxemissionfactor_s\ [\text{tSOx/MWh}]\ (65)$$

$$SOxfut_{tot}[\text{tSOx/time}] = \sum_s SOxfut_s\ (66)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $SOxemissionfactor_s$ represents the factor that correlates the primary energy consumption to the SOx production in the future scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.10 specific SOx emission future (ENV 2.4 sSOxfut)

According to (66) the specific SOx emission can be calculated in the future scenario considering (67).

$$sSOxfut_{tot}[\text{tSOx/time/m}^2] = \frac{SOxfut_{tot}}{m^2}\ (67)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.11 SOx emission variation from baseline (ENV 2.5 SOxvar)

The SOx emission variation from baseline represents the variation in percentage of the total SOx emitted from baseline to future scenario.

$$SOxvar_{tot}[\%] = \left[\frac{SOxfut_{tot}}{SOxbase_{tot}} - 1\right] \times 100\ (68)$$

4.2.12 SOx emission savings (ENV 2.6 SOxsav)

The SOx emission saving is calculated as the difference between the future scenario and the baseline scenario values.

$$SOxsav_{tot}[\text{MWh/time}] = SOxbase_{tot} - SOxbase_{fut}\ (69)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.2.13 NOx emission baseline (ENV 3.1 NOxbase)

The total NOx emitted by each system in the baseline reference scenario is directly correlated with the primary energy consumption through a NOx emission factor that can be input directly by the end-user of the SO WHAT tool or retrieved as default value from a dedicated database. According to (1) and (2) the NOx emitted can be expressed per each source considered in the system (70) or considering the total amount (71).

$$NOxbase_s[\text{tNOx/time}] = PECbase_s[\text{MWh/time}] * NOxemissionfactor_s[\text{tNOx/MWh}] \ (70)$$

$$NOxbase_{tot}[\text{tNOx/time}] = \sum_s NOxbase_s \ (71)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $NOxemissionfactor_s$ represents the factor that correlates the primary energy consumption to the NOx production in the baseline scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.14 specific NOx emission baseline (ENV 3.2 s NOxbase)

According to (71) the specific NOx emission can be calculated in the baseline reference scenario considering (72).

$$sNOxbase_{tot}[\text{tNOx/time/m}^2] = \frac{NOxbase_{tot}}{m^2} \ (72)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.15 NOx emission future (ENV 3.3 NOxfut)

As per the reference baseline scenario, the NOx emitted in the future scenario can be calculated with (73) and (74).

$$NOxfut_s[\text{tNOx/time}] = PECfut_s[\text{MWh/time}] * NOxemissionfactor_s[\text{tNOx/MWh}] \ (73)$$

$$NOxfut_{tot}[\text{tNOx/time}] = \sum_s NOxfut_s \ (74)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $NOxemissionfactor_s$ represents the factor that correlates the primary energy consumption to the NOx production in the future scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.16 specific NOx emission future (ENV 3.4 s NOxfut)

According to (74) the specific NOx emission can be calculated in the future scenario considering (75).

$$sNOxfut_{tot}[\text{tNOx/time/m}^2] = \frac{NOxfut_{tot}}{m^2} \text{ (75)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.17 NOx emission variation from baseline (ENV 3.5 NOxvar)

The NOx emission variation from baseline represents the variation in percentage of the total NOx emitted from baseline to future scenario.

$$NOxvar_{tot}[\%] = \left[\frac{NOxfut_{tot}}{NOxbase_{tot}} - 1\right] \times 100 \text{ (76)}$$

4.2.18 NOx emission savings (ENV 3.6 NOxsav)

The NOx emission saving is calculated as the difference between the future scenario and the baseline scenario values.

$$NOxsav_{tot}[\text{MWh/time}] = NOxbase_{tot} - NOxbase_{fut} \text{ (77)}$$

Where:

- *time* represents the resolution of the reference period of calculation

4.2.19 PM10 emission baseline (ENV 4.1 PM10base)

The total PM10 emitted by each system in the baseline reference scenario is directly correlated with the primary energy consumption through a PM10 emission factor that can be input directly by the end-user of the SO WHAT tool or retrieved as default value from a dedicated database. According to (1) and (2) the PM10 emitted can be expressed per each source considered in the system (78) or considering the total amount (79).

$$PM10base_s[\text{tPM10/time}] = PECbase_s[\text{MWh/time}] * PM10emissionfactor_s [\text{tPM10/MWh}] \text{ (78)}$$

$$PM10base_{tot}[\text{tPM10/time}] = \sum_s PM10base_s \text{ (79)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- $PM10emissionfactor_s$ represents the factor that correlates the primary energy consumption to the NOx production in the baseline scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.20 specific PM10 emission baseline (ENV 4.2 sPM10base)

According to (79) the specific PM10 emission can be calculated in the baseline reference scenario considering (80).

$$sPM10base_{tot}[\text{tPM10/time/m}^2] = \frac{PM10base_{tot}}{m^2} \text{ (80)}$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.21 PM10 emission future (ENV 4.3 PM10fut)

As per the reference baseline scenario, the PM10 emitted in the future scenario can be calculated with (81) and (82).

$$PM10fut_s[\text{tPM10/time}] = PECfut_s[\text{MWh/time}] * PM10emissionfactor_s\,[\text{tPM10/MWh}]\,(81)$$

$$PM10fut_{tot}[\text{tPM10/time}] = \sum_s PM10fut_s\,(82)$$

Where:

- *time* represents the resolution of the reference period of calculation
- $PM10emissionfactor_s$ represents the factor that correlates the primary energy consumption to the PM10 production in the future scenario and is an input for the tool that can be either edited directly by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

4.2.22 specific PM10 emission future (ENV 4.4 sPM10fut)

According to (82) the specific PM10 emission can be calculated in the future scenario considering (83).

$$sPM10fut_{tot}[\text{tPM10/time/m}^2] = \frac{PM10fut_{tot}}{m^2}\,(83)$$

Where:

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered

4.2.23 PM10 emission variation from baseline (ENV 4.5 PM10var)

The PM10 emission variation from baseline represents the variation in percentage of the total PM10 emitted from baseline to future scenario.

$$PM10var_{tot}[\%] = \left[\frac{PM10fut_{tot}}{PM10base_{tot}} - 1\right] \times 100\,(84)$$

4.2.24 PM10 emission savings (ENV 4.6 PM10sav)

The PM10 emission saving is calculated as the difference between the future scenario and the baseline scenario values.

$$PM10sav_{tot}[\text{MWh/time}] = PM10base_{tot} - PM10base_{fut}\,(85)$$

Where:

- *time* represents the resolution of the reference period of calculation

4.2.25 Noise pollution variation from baseline (ENV 5.1 dBpollvar)

Noise pollution variation is the sum for each sector and source of the difference between noise pollution in future and baseline scenarios compared to the value of the baseline scenario.

$$dBpollvar_{tot}[\%] = \sum_s \left(\frac{dBpollfuture_s}{dBpollbaseline_s} - 1 \right) * 100 \ (86)$$

Where:

- $dBpollfuture_s$ represents the noise pollution referred to each energy conversion technology in the future scenario and is an input from the end-user
- $dBpollbaseline_s$ represents the noise pollution referred to each source utilization in the baseline reference scenario and is an input from the end-user

4.3   Social domain

4.3.1   Energy poverty baseline (SO 1.1 Enpovbase)

The calculation of the energy poverty indicator in the baseline reference scenario is done as the ratio between the total expenditure required to the purchase of the different fuels (final energy consumption) and the difference between the annual income and the annual expenses per square meter in the baseline scenario.

$$Enpovbase_{tot} \ [\text{€/time/m}^2] = \frac{\sum_s(FECbase_s*energy\ tariff_s)}{\frac{(annual\ income\ base - annual\ expenses\ base)}{m^2}} \ (87)$$

Where

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered
- $energy\ tariff_s$ represents the fuel cost in [€/MWh] related to each source
- *annual income base* represents the annual income in € for the residents of the area under study in the baseline scenario
- *annual expenses base* represents the annual output in € from the residents of the area under study in the baseline scenario

4.3.2   Energy poverty future (SO 1.2 Enpov fut)

As per the reference baseline scenario, in (88) the energy poverty value in the future scenario is calculated using (88).

$$Enpovfut_{tot} \ [\text{€/time/m}^2] = \frac{\sum_s(FECfut_s*energy\ tariff_s)}{\frac{(annual\ income\ base - annual\ expenses\ base)}{m^2}} \ (88)$$

Where

- *time* represents the resolution of the reference period of calculation
- *m²* being the total area under investigation or the building/group of building gross floor area depending by the type of boundary considered
- $energy\ tariff_s$ represents the fuel cost in [€/MWh] related to each source
- *annual income base* represents the annual income in € for the residents of the area under study in the baseline scenario

- *annual expenses base* represents the annual output in € from the residents of the area under study in the baseline scenario

4.3.3 Energy poverty variation from baseline (SO 1.1 Enpovvar)

The energy poverty variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$Enpovvar_{tot}[\%] = \left[\frac{Enpovfut_{tot}}{Enpovbase_{tot}} - 1\right] \times 100 \ (89)$$

4.3.4 Security of supply baseline (SO 2.1 ssbase)

The security of supply indicator is defined as the ratio between the final energy consumption of each local source in the area of investigation and the total final energy availability of the source in the time frame considered. The latter indicator comes from the analysis performed by the SO WHAT module that is dedicated to the identification and evaluation of local sources in terms of geographical position and final energy available in a selected time frame.

$$ssbase_{\ local\ s}[\%] = \left(\frac{FECbase_{local\ s}}{FEavailability_{local\ s}}\right) * 100 \ (90)$$

4.3.5 Security of supply future (SO 2.2 ssfut)

As per the baseline reference scenario, the security of supply in the future scenario can be calculated with (91).

$$ssfut_{\ local\ s}[\%] = \left(\frac{FECfut_{local\ s}}{FEavailability_{local\ s}}\right) * 100 \ (91)$$

4.3.6 Security of supply variation from baseline (SO 2.3 ssvar)

The security of supply variation from baseline represents the variation in percentage of the indicator from baseline to future scenario.

$$ssvar_{local\ s}\ [\%] = \left(\frac{ssfut_{local\ s}}{ssbase_{local\ s}} - 1\right) * 100 \ (92)$$

4.3.7 Job increase (SO 3.1 jobin)

The increase of job due to the supposed enhancement interventions in the creation of future scenarios, is calculated based on the related investment. The indicator is calculated as the sum per each source of the related investment cost in the future scenario multiplied by a factor that depends from the type of source considered.

$$Jobin = \sum_s(CAPEXs * jf_s) \ (93)$$

Where:

- jf_s represents a factor expressed in [job/€ invested] that considers the new employments related to the implementation or renovation of technologies in the future scenario and that can be input by the end-user or automatically retrieved as default values by the SO WHAT tool "Central database".

5 Conclusions

The algorithms described in this document will be integrated in the SO WHAT tool to provide the end-user with a set of indicators able to evaluate the performance of different scenarios in the framework of waste heat and cold recovery from industrial facility. The indicators have been divided into four main domains (energetic, environmental, economic and social) that are strictly related to each other and can be used to design future scenarios according to general design criteria that group some of them together.

Following deliverables, D4.5 "Delivery of the UX/UI design" and D4.7 "Delivery of dashboard for non-expert and decision makers", will clarify how the GUI will be designed and developed providing the possibility to easily input the required parameters, retrieve them for the SO WHAT "Central Database", select different design criteria and visualize the results.

Due to the different possibilities of utilization of the GUI from the different stakeholders, end-user of the tool (mainly the three types of stakeholders identified as industrial facility, community and DHCN operator) and to the possibility to use the same metrics for different purposes, the testing and refinement camping foreseen by task 5.2 will be crucial to fine tune the algorithms and finally fix all parameters.