iWAYS
innovative water recovery solutions

D6.3. Common validation methodology – Public version

[31/10/2022]

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°958274

Technical References

Project Acronym	iWAYS
Project Title	Innovative WAter recoverY Solutions through recycling of heat, materials and water across multiple sectors
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Project Duration	4 years

Deliverable No.	D6.3
Dissemination level [1]	PU
Work Package	6
Task	6.2
Lead beneficiary	PWR – UNIMORE - BUL
Contributing beneficiary(ies)	
Due date of deliverable	2022.05.31
Actual submission date	2022.12.23

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
V0.1			
V0.2			
V0.3			
V0.4			

Summary

Summary of Deliverable

This document compiles a description of the target aspects that are going to be evaluated within iWAYS project; the methodology of evaluation; the definition of key performance indicators (KPIs) to monitor those aspects; and the characteristics of the measured variables.
The main impacts of the iWAYS project that will be monitored are: sensible energy recovered ratio, primary energy savings, the reduction of greenhouse gas emissions and pollutants, the water recovered due to the installation of the iWAYS system and the subsequent reduction of the water consumption within the process, and the reduction of energy cost triggered by the project. The impact of the iWAYS process will be monitored with specific KPIs.
However, as ceramic, chemical and ceramic representative demo cases have each own specific performance peculiarities, specific KPIs have been defined to monitor their performance. Based on those specific KPIs and considering the common main impacts to be evaluated, some common KPIs are defined for the three demo cases to evaluate the iWAYS heat and water recovery performance in a common way.
Defined KPIs are the values to monitor the target impacts defined in the iWAYS proposal and they will be directly obtained based on measurements of the project before and after the iWAYS installation will be commissioned. Calculating the difference of the KPIs values before and after the installation the target impact values will be verified.
The methodology and KPIs described in this document will be used in WP7 for the 3 use cases installations validation.

Sommario

Introduction

The aim of this document is to describe the target aspects that are going to be evaluated within iWAYS project; the methodology of evaluation; the definition of key performance indicators (KPIs) to monitor those aspects; and the characteristics of the measured variables.
In the first chapter the main impacts of the iWAYS project that will be monitored are described. The description of the methodology and the review of ISO 50006 and EN16247-part3 standards to obtain guidelines and references to define the methodology and the KPIs to monitor the iWAYS project impact are described in chapter 2.
In Chapter 3, the key performance indicators are presented. In the first section of the chapter the common KPIs are described; then, the specific KPIs that will be used in each demo case are reported. 3.

Chapter 1: Target aspects to evaluate

For estimating iWAYS project performance indicators the recommended approach given in the Guidelines for the Calculation of Project Performance Indicators edited by the European Commission [1] have been followed. The first step of this approach is to define the scope of iWAYS project and to establish the expected project impacts.
Within the scope of iWAYS project the objectives reported in the GA are the following ones:

- SO1: To create a framework streamlining the design process of iWAYS systems with regards to customized installations to condensate water from exhausts and purify the recovered water
- SO2. Realizing water closed loops and a substantial reduction in freshwater consumption
- SO3. Achieving a substantial reduction in thermal waste and process energy requirements
- SO4: Recovery of materials by valorising challenging exhaust streams
- SO5: Reclaiming, treating and reutilizing water in industrial processes
- SO6: Utilization of alternative water resources and rainwater harvesting
- SO7: Real time smart monitoring of recycled water and gaseous emissions composition
- SO8: Develop a methodology to select the best available synergies
- SO9: Streamlining the iWAYS solutions and accelerating the commercialization process

Based on those objectives the project performance indicators that will be used in iWAYS project have been defined and they are shown in the following tables. Those indicators are the main target aspects to be evaluated in the three demo cases. For their evaluation some variables will have to be measured, calculated and estimated. In the following chapters the methodology for measurement and calculations and the common and specific key performance indicators (KPI) of each demo case are described.

Recovery of water, energy and material due to the iWAYS systems

		Ceramics (CON)	Chemicals (ALUFLUOR)	Steel (TTI)
Before	Water recovery (m^3/y)	none	none	none
	Energy recovery (GWh/y)	none	none	none
	Material recovery (t/y)	none	none	none
iWAYS	Water recovery (m^3/y)	10,000	3,500	3,850
	Energy recovery (GWh/y)	6	5.18	0,72
	Material recovery (t/y)	0.3	70	0.1

Reduction of Greenhouse gas emissions due to the iWAYS systems

	Ceramics (CON)	Chemicals (ALUFLUOR)	Steel (TTI)
Water saved (m^3/y)	10,000	3,500	3,850
CO2 eq saved (t/y)	2,582	2,245	311

Chapter 2: Validation methodology

The method to quantify the impacts of the project will be the Bottom-up method [1] where the values of each target impact defined in the iWAYS proposal described in chapter 1 will be directly obtained based on measurements of the project.

Each demo case is implementing a monitoring system to collect information about the temperatures and flow rates of streams and this system will be extend with additional variables to obtain the required information to evaluate the target impacts of the project.

As each application has different characteristics specific KPIs have been defined to monitor and evaluate each demo case energy performance.

The first step for the common methodology has been to define a common nomenclature and the units to be used by all the partners; afterwards each specific Key Performance Indicators required to monitoring in each demo case have been defined taking into account its application ' s own specific characteristics. That definition includes the description of the variables that have to be measured, its accuracy and error propagation (see chapter 4). From those specific Key Performance Indicators, the common Key performance indicators have been defined in order to evaluate the impacts of the project.

Those target impacts, described as common KPIs, will be obtained based on direct measure variables installation before and after the iWAYS system installation. The difference of the values obtained before and after the iWAYS system installation will provide the saving values obtained due to the iWAYS development.
The sensors and the methodology of the measurement of each parameter (continuous or discontinuous, frequency…) will be described in Deliverable 3.3.

The project baseline will be obtained by the sensors and the measurements carried out before the installation of the iWAYS technology. Indeed, experimental campaigns have been already carried out in each demo site to characterize the exhaust flow (flowrate, temperature, composition, humidity) and the condensed water composition.

Savings = (Baseline Period Energy − Reporting Period Energy)

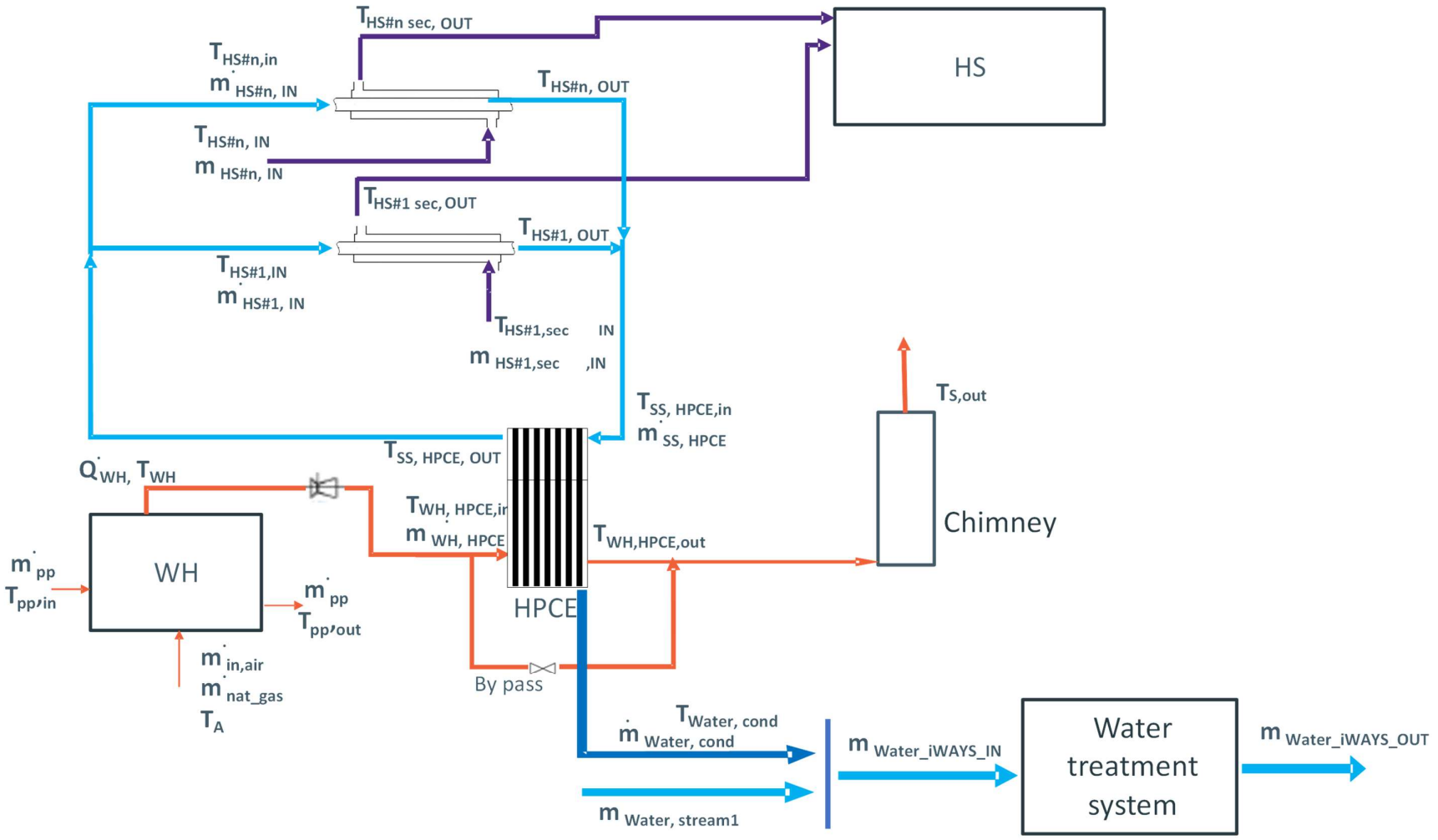

Figure 1 – General layout of the iWAYS system and main monitored parameters

Chapter 3: KPIs

Period of data evaluation

There are two time periods for the monitoring of the process variables. The first period is necessary for the definition of the process baseline. The process baseline definition already started with the experimental campaign carried out for the characterization of the exhaust streams and the condensed water. The baseline definition will continue once the sensors will be installed.
The monitoring target period of the iWAYS system performance is 12 months. The commissioning of the iWAYS solution is planned before M36; thus, 12 months will be available until the end of the project for the monitoring of the performance. After the commissioning of the iWAYS system, data will be monitored on a monthly basis for the calculation of the KPIs.

3.1) Evaluated common key performance indicators

The elements that form the iWAYS integrated system are:
1. The HPCE (Heat Pipe Condensing Economizer)
2. The waste heat source process (WH)
3. The heat sink process or processes (HS): the processes where the recovery heat is used.
4. Intermediate heat exchanger (IHE) (optional). This element is used when HPCE secondary stream cannot be directly introduced in the heat sink process and a intermediate carrier stream is used to deliver the heat in the final heat sink process. More than one intermediate heat exchanger can be introduced in the process.
5. Water treatment system. The water purification system that will treat the condensed water and the other recovered streams for reusing it within the process.
5. Heat storage (optional). When the HS and WH processes are not simultaneous or when the available waste energy is higher than the load energy, a heat storage system could be used to manage the timing of the use of recovered heat.
6. Balance of plant elements (BOP): all the auxiliary components (fans, pumps, valves, etc.) needed in the iWAYS system to recover and transfer the waste heat energy from the source process to the sink processes.

Each of those elements has defined their own performance indicators to monitor their performance at component level and they are defined according to the specific application characteristics. The common key performance indicators to evaluate the project target values of sensible energy recovered ratio; the primary energy savings triggered by the project; the reduction of pollutants and greenhouse gas emissions, the reduction in the water consumption, the reduction of energy cost triggered by the project, are based on the performance of those elements.

In the following, the parameters and variables that should be monitored for the KPIs calculation are displayed and the associated nomenclature is presented.

Table 1 – Nomenclature and sensors needed for the KPIs' calculation

Variable Type	*Meaning*	*Units*	*Method of calculation*
$p_{PS,HPCE,IN}$	Pressure of the primary stream at the inlet of the HPCE	bar, Pa	Measured (sensor) – Demo Case 1 and Demo Case 2
$p_{PS,HPCE,OUT}$	Pressure of the primary stream at the outlet of the HPCE	bar, Pa	Measured (sensor) – Demo Case 1 and Demo Case 2
$p_{SS,HPCE,IN}$	Pressure of the secondary stream at the inlet of the HPCE	bar, Pa	Measured (sensor) – ALL demo cases
$p_{SS,HPCE,OUT}$	Pressure of the secondary stream at the outlet of the HPCE	bar, Pa	Measured (sensor) – ALL demo cases
$\dot{m}_{WH,HPCE}$	Mass flow rate of the exhaust source (waste heat) flowing through the HPCE	kg/s	Measured (sensor) – Demo Case 1 and Demo Case 2
$T_{WH,HPCE,IN}$	Temperature of the exhaust source (waste heat) at the inlet of the HPCE	°C	Measured (sensor) – Demo Case 1 and Demo Case 2
$T_{WH,HPCE,OUT}$	Temperature of the exhaust source (waste heat) at the outlet of the HPCE	°C	Measured (sensor) - – Demo Case 1 and Demo Case 2
Humidity	Humidity content in the exhaust gases before HPCE	% (mass or volume)	Measured (sensor) if needed.
XX	Element XX contained in the exhaust gases	g/h	The element to be measured will depend on the democase (they will be defined in the following section). In general, this value will be measured (sensor): the sensor will depend on the pollutant, e.g. HF the proposed methodology is TDLas. They will be described in Deliverable 3.3.
$\dot{m}_{Water\_cond}$	Water flowrate condensed from the exhaust gases in the HPCE	l/h – l/s kg/h – kg/s	Measured (sensor) – Demo Case 1 and Demo Case 2
T_{Water_cond}	Temperature of the condensed water	°C	Measured (sensor) – Demo Case 1 and Demo Case 2
$\dot{m}_{Water,stream1}$	Water flowrate recovered from other sources	l/h – l/s kg/h – kg/s	Measured (sensor) / or calculated as difference - ALL
$\dot{m}_{Water,iWAYS_{IN}}$	Water flowrate recovered and flowing in the iWAYS treatment system	l/h – l/s kg/h – kg/s	Measured (sensor) - ALL
$\dot{m}_{Water,iWAYS\_OUT}$	Water flowrate recycled exiting from the iWAYS system	l/h – l/s kg/h – kg/s	Measured (sensor) - ALL
$El\_con_{\_iWAYS\_water\_IN}$	Electrical Conductivity of iWAYS inlet water	µS/cm	Measured (sensor) – Demo Case 1

$El\_con_{\_permeate\_NF}$	Electrical Conductivity of NF Permeate water	µS/cm	Measured (sensor) – Demo Case 1
$TUR_{iWAYS\_water\_IN}$	Turbidity of iWAYS inlet water	NTU - mg/l	Measured (sensor) – Demo case 2
$TUR_{iWAYS\_water\_OUT}$	Turbidity of iWAYS Outlet water	NTU - mg/l	Measured (sensor) – Demo Case 2
$HCa_{iWAYS\_water\_IN\_}$	Calcium Hardness of iWAYS inlet water	°F - mg/l	Measured (sensor) – Demo Case 2
$HCa_{iWAYS\_water\_OUT\_}$	Calcium Hardness of iWAYS outlet water	°F - mg/l	Measured (sensor) – Demo Case 2
YY	Element YY contained in the condensed water	g/h	Measured (sensor). The element to be measured will depend on the democase (they will be defined in the following section). In general, this value will be measured (sensor): the sensor will depend on the pollutant. They will be described in Deliverable 3.3.
$\dot{m}_{SS,HPCE}$	Mass flow rate of the thermal fluid flowing in the secondary section of the HPCE	kg/s	Measured (sensor) - ALL
$T_{SS,HPCE,IN}$	Temperature of the thermal fluid stream at the inlet of the HPCE	°C	Measured (sensor) - ALL
$T_{SS,HPCE,OUT}$	Temperature of the thermal fluid stream at the at the outlet of the HPCE	°C	Measured (sensor) - ALL
$\dot{m}_{HS\#1}$	Mass flow rate of the thermal fluid flowing in first intermediate heat exchanger (if any)	kg/s	measured (sensor) - ALL
$\dot{m}_{HS\#N}$	Mass flow rate of the thermal fluid flowing in N intermediate heat exchanger (if any)	kg/s	measured (sensor) – ALL
$T_{HS\#1,IN}$	Temperature of the thermal fluid stream at the inlet of the first intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
$T_{HS\#1,OUT}$	Temperature of the thermal fluid stream at the outlet of the first intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
$T_{HS\#N,IN}$	Temperature of the thermal fluid stream at the inlet of the N intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
$T_{HS\#N,OUT}$	Temperature of the thermal fluid stream at the outlet of the N intermediate heat exchanger (if any)	°C	Measured (sensor) – ALL
$T_{HS\#1,sec,IN}$	Temperature of the secondary stream at the	°C	Measured (sensor) - ALL

	inlet of the first intermediate heat exchanger (if any)		
$T_{HS\#1,sec,OUT}$	Temperature of the secondary stream at the outlet of the first intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
$T_{HS\#N,sec,IN}$	Temperature of the secondary stream at the inlet of the N intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
$T_{HS\#N,sec,OUT}$	Temperature of the secondary stream at the outlet of the N intermediate heat exchanger (if any)	°C	Measured (sensor) - ALL
Q	Thermal energy	MWh	Calculated
$\dot{Q}$	Thermal power	kW	Calculated
LHV_{fuel}	Lower heating value of a fuel	kJ/kg	Literature
Cp	Specific heat of a fluid	kJ/kg K	Literature
Pel	Electric power	kW	Measured - ALL
Een	Electric energy	kWh	Calculated
$h_{p,a}$	Hours of plant activity per reporting period	h/month h/year	Measured - ALL
$Coeff_{CO_2}$	Quantity of CO_2 per kg of fuel	kg_{CO2}/kg_{fuel}	Literature
$Cost_{CO_2\_emission}$	Emission CO_2 cost	€/ t_{CO2}	Literature
$\dot{m}_{fuel}$	Mass flow rate of consumed fuel	kg/s – Nm^3/h / Sm^3/h	measured (sensor) if possible - ALL
$Cost_{fuel}$	Cost of the fuel	€/kg	Average value of the reported period (month??)
$Cost_{water}$	Cost of the water withdrawal	€/l - €/t	Average value of the reported period (month??)
$Cost_{el.energy}$	Cost of the electric energy	€/kWh	Average value of the reported period (month??)
Sav	Saving	€	Calculated
$Tamb$	Reference ambient temperature	°C	Defined equal to 25 °C.
Eff	Efficiency	%	

Table 2 – iWAYS common KPIs

iWAYS technology performance KPIs					
	Common Kpi's	***Descriptive name***	***Formula***	***Units***	***Notes***
1	Primary stream (waste source) thermal power recovered	$\dot{Q}_{WH}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{WH,HPCE,out})$	kW	Thermal power recovered from the waste heat source
2	Primary stream (waste source) available thermal power	$\dot{Q}_{WH\_available}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{amb})$	kW	Thermal power available in the exhaust gases
3	Efficiency of the heat recovery	Eff_{rec_heat}	$\frac{\dot{Q}_{WH}}{\dot{Q}\_WH\_available} * 100$	%	Percentage of the recovered thermal power on the available power
4	Thermal power recovered by the secondary stream (thermal fluid)	$\dot{Q}_{SS\_rec}$	$\dot{m}_{SS,HPCE} * cp_{SS} * (T_{SS,HPCE,in} - T_{SS,HPCE,out})$	kW	Thermal power recovered by the thermal fluid in the condenser section of the HPCE
4	Thermal power exploited in the heat sinks. Saved thermal power.	$\dot{Q}_{exp,HS}$	$\dot{m}_{HS\#1} * cp_{thermalfluid} * (T_{HS\#1,in} - T_{HS\#1,out}) + \ldots + \dot{m}_{HS\#N} * cp_{thermalfluid} * (T_{HS\#N,in} - T_{HS\#N,out})$	kW	Thermal power exploited in the heat sinks
5	Primary stream recovered energy	Q_{WH}	$\int_0^{hp,a} \dot{Q}_{WH} dt$	MWh/reporting period (month?)	Thermal energy recovered in the exhaust gases (waste source). It derives from the KPI Nr.1 and the operating hours of the HPCE.
6	Secondary stream recovered energy (thermal fluid).	$Q_{SS,rec}$	$\int_0^{hp,a} \dot{Q}_{SS,rec} dt$	MWh/reporting period (month?)	Thermal energy recovered in secondary stream of the HPCE. It derives from the KPI Nr.3 and the operating hours of the HPCE.
7	Thermal energy exploited in the heat sinks. Saved thermal energy.	$Q_{exp,HS}$	$\int_0^{hp,a} \dot{Q}_{exp,HS} dt$	MWh/reporting period (month?)	Thermal energy exploited in the heat sinks. It derives from the KPI Nr.4 and the operating hours of the heat sink(s).
8	Efficiency of the heat exploitation system	Eff_{expl_syst}	$\frac{\dot{Q}_{exp,HS}}{\dot{Q}_{SS\_rec}} * 100$	%	Efficiency of the heat exploitation. Thermal power exploited with the respect to the thermal power recovered.
9	Electric energy consumption of the BOP components of the heat recovery section.	$E_{en\_BOP\_HeatRec}$	$\int_0^{hp,a} (P_{el\_BOP\_fan} + \cdots + P_{el_{BO\ pump}}) dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS system heat recovery section (fan, valves, pumps…)

10	Fuel consumption mass flow rate without iWAYS	$\dot{m}_{fuel}$	*Measured by sensors (flow meter for natural gas installed in the stage process where heat will be recovered)*	kg/s or Nm3/h	Natural gas consumption in the target process
11	Fuel consumption mass flow rate with iWAYS	$\dot{m}_{fuel\_iWAYS}$	*Measured by sensors (flow meter for natural gas)*	kg/s or Nm3/h	Natural gas consumption in the target process
12	Fuel flowrate Saved with iWAYS	$\dot{m}_{fuel\_saved}$	Method 1: $\dot{m}_{fuel}$ - $\dot{m}_{fuel\_iWAYS}$ (if KPIs 11 -12 are available) Method 2: $\frac{\dot{Q}_{exp,HS}}{LHV\_fuel}$	kg/s	The saved fuel can be calculated from the KPI Nr.4 and the lower heating value of the fuel.
13	Fuel saved over the reporting period	*Sav_fuel*	$\int_0^{hp,a} \dot{m}_{fuel\_saved} dt$	kg/reporting period (month??)	
14	Total carbon dioxide saved	*Sav_CO₂*	$Sav\_fuel * coeff_{CO_2}$	t/reporting period	
15	Humidity of the gaseous emission	*H*	Measured.	% (mass or volume)	
16	Condensed water flowrate in the HPCE	$\dot{m}_{Water\_cond}$	Measured by a sensor or with other system.	l/h – l/s kg/h – kg/s	
17	Humidity reduction with iWAYS	H_{red}	$\frac{H_{before\_iWAYS} - H_{iWAYS}}{H_{before\_iWAYS}} * 100$	%	This formula calculates the difference between the humidity of the exhaust before iWAYS (experimental campaign as reference) and the humidity of the exhaust after the iWAYS system installation.
18	Element XX contained in the exhaust gases	XX	Measured (sensor)	g/h	The element to be measured will depend on the democase. In the following section the elements to be monitored will be defined per each democase.
19	Element XX reduction with iWAYS	XX_{red}	$\frac{XX_{before\_iWAYS} - XX_{iWAYS}}{XX_{before\_iWAYS}} * 100$	%	This formula calculates the percentage difference between the Element XX contained in the exhaust before iWAYS (experimental campaign as reference) and the element XX contained in the exhaust after the iWAYS system installation.
20	Water flowrate recovered from other sources	$\dot{m}_{Water,stream1}$	Measured (sensor) / or calculated as difference from KPI 20 and KPI 16	l/h – l/s kg/h – kg/s	
21	Water flowrate recovered and flowing in the iWAYS treatment system	$\dot{m}_{Water,iWAYS_{IN}}$	Measured (sensor)	l/h – l/s kg/h – kg/s	

22	Water flowrate recycled exiting from the iWAYS system	$\dot{m}_{Water,iWAYS\_OUT}$	Measured (sensor)	/h – l/s kg/h – kg/s	
23	Water recovery efficiency	$Eff_{water\_recovery}$	$\frac{\dot{m}_{Water,iWAYS\_OUT}}{\dot{m}_{Water,iWAYS_{IN}}} * 100$	%	
24	Water saved with iWAYS system	Sav_water	$\int_0^{hp,a} \dot{m}_{Water,iWAYS\_OUT}\, dt$	l/ reporting period (month?)	Saved water according to the iWAYS technology.
25	Element YY contained in condensed water	YY	Measured (sensor)	g/h	The element to be measured will depend on the democase. In the following section the elements to be monitored will be defined per each democase.
26	Element YY reduction with iWAYS	YY_{red}	$\frac{YY_{before\_iWAYS} - YY_{iWAYS}}{YY_{before\_iWAYS}} * 100$	%	This formula calculates the percentage difference between the Element YY contained in the water before iWAYS (experimental campaign as reference) and the element YY contained in the exhaust after the iWAYS system installation.
27	Electric energy consumption of the BOP components of the water treatment system	$E_{en\_BOP\_WaterRec}$	$\int_0^{hp,a} (P_{el\_BOP\_SKID1} + \cdots + P_{el_{BOP\_SKID2}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS water treatment system (ultrafiltration, nanofiltration, pumps, valves…)

iWAYS economic KPIs

1	Fuel cost saving	*C_Sav_fuel*	Sav_fuel * Cost_fuel	€ / reporting period (month?)	
2	Total CO_2 cost saving	*C_Sav_CO2*	*Sav_CO2* * $Cost_{CO_2\_emission}$	€/ reporting period (month??)	
3	Water cost saving	C_Sav_Water	*Sav_water* * $Cost_{water}$	€/ reporting period (month??)	
4	Total saved cost	C_Sav	*C_Sav_fuel*+ C_Sav_Water+ C_Sav	€/ reporting period (month??)	
5	iWAYS technology operating cost	C_op_iWAYS	($E_{en\_BOP\_HeatRec}$ * $E_{en\_BOP\_WaterRec}$) * $Cost_{el.energy}$	€/ reporting period (month??)	
6	Revenue from iWAYS technology	Rev_iWAYS	C_Sav - C_op_iWAYS	€/ reporting period (month??)	

7	Payback of the iWAYS technology	Payback		Months/year	
iWAYS other KPIs					
1	Number of potential for symbiosis with surrounding industrial plants & municipalities in all use cases.				
2	Number of multi-stakeholders workshop to disseminate the iWAYS project and technologies.				
3	Number of guided tours through upgraded industries				
4	Number of identified additional number sources for replication				
5	Number of journalistic articles				
6	Number of scientific papers published on international journal				
7	Number of Scientific conferences for the promotion of iWAYS.				
8	Number of interviews released with users and stakeholder experts				

3.2) Specific KPIs

The processes of each demo case are different and each iWAYS design has its own peculiarities. Therefore, each demo case has defined its own KPIs to evaluate the performance of the technology. In this chapter those specific KPIS are described.

- Atlas Concorde

The specific KPIs for Atlas Concorde will include the above mentioned performance KPIs with some parameters for the exhaust and the water recovered that are specific for the ceramic process.

Table 3 – Atlas Concorde Specific KPIs.

iWAYS technology performance KPIs					
Nr	***Kpi***	***Descriptive name***	***Formula***	***Units***	***Notes***
1	Primary stream (waste source) thermal power recovered	$\dot{Q}_{WH}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{WH,HPCE,out})$	kW	Thermal power recovered from the waste heat source
2	Primary stream (waste source) available thermal power	$\dot{Q}_{WH\_available}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{amb})$	kW	Thermal power available in the exhaust gases
3	Efficiency of the heat recovery	Eff_{rec_heat}	$\frac{\dot{Q}_{WH}}{\dot{Q}\_WH\_available} * 100$	%	Percentage of the recovered thermal power on the available power
4	Thermal power recovered by the secondary stream (thermal fluid)	$\dot{Q}_{SS\_rec}$	$\dot{m}_{SS,HPCE} * cp_{SS} * (T_{SS,HPCE,in} - T_{SS,HPCE,out})$	kW	Thermal power recovered by the thermal fluid in the condenser section of the HPCE
4	Thermal power exploited in the heat sinks. Saved thermal power.	$\dot{Q}_{exp,HS}$	$\dot{m}_{HS\#1} * cp_{thermalfluid} * (T_{HS\#1,in} - T_{HS\#1,out}) + \ldots + \dot{m}_{HS\#N} * cp_{thermalfluid} * (T_{HS\#N,in} - T_{HS\#N,out})$	kW	Thermal power exploited in the heat sinks
5	Primary stream recovered energy	Q_{WH}	$\int_0^{hp,a} \dot{Q}_{WH} dt$	MWh/reporting period (month?)	Thermal energy recovered in the exhaust

					gases (waste source). It derives from the KPI Nr.1 and the operating hours of the HPCE.
6	Secondary stream recovered energy (thermal fluid).	$Q_{SS,rec}$	$\int_0^{hp,a} \dot{Q}_{SS,rec} dt$	MWh/reporting period (month?)	Thermal energy recovered in secondary stream of the HPCE. It derives from the KPI Nr.3 and the operating hours of the HPCE.
7	Thermal energy exploited in the heat sinks. Saved thermal energy.	$Q_{exp,HS}$	$\int_0^{hp,a} \dot{Q}_{exp,HS} dt$	MWh/reporting period (month?)	Thermal energy exploited in the heat sinks. It derives from the KPI Nr.4 and the operating hours of the heat sink(s).
8	Efficiency of the heat exploitation system	Eff_{expl_syst}	$\frac{\dot{Q}_{exp,HS}}{\dot{Q}_{SS\_rec}} * 100$	%	Efficiency of the heat exploitation. Thermal power exploited with the respect to the thermal power recovered.
9	Electric energy consumption of the BOP components of the heat recovery section.	$E_{en\_BOP\_HeatRec}$	$\int_0^{hp,a} (P_{el\_BOP\_fan} + \cdots + P_{el_{BO\ pump}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS system heat recovery section (fan, valves, pumps…)

10	Fuel consumption mass flow rate without iWAYS	$\dot{m}_{fuel}$	Measured by sensors.	kg/s or Nm3/h	Natural gas consumption in the target process
11	Fuel consumption mass flow rate with iWAYS	$\dot{m}_{fuel\_iWAYS}$	Measured by sensor	kg/s or Nm3/h	Natural gas consumption in the target process
12	Fuel flowrate Saved with iWAYS	$\dot{m}_{fuel\_saved}$	Method 1: $\dot{m}_{fuel}$ - $\dot{m}_{fuel\_iWAYS}$ (if KPIs 11 -12 are available) Method 2: $\frac{\dot{Q}_{exp,HS}}{LHV\_fuel}$	kg/s	The saved fuel can be calculated from the KPI Nr.4 and the lower heating value of the fuel.
13	Fuel saved over the reporting period	*Sav_fuel*	$\int_0^{hp,a} \dot{m}_{fuel\_saved} dt$	kg/reporting period (month??)	
14	Total carbon dioxide saved	*Sav_CO2*	$Sav\_fuel * coeff_{CO_2}$	t/reporting period	
15	Humidity of the gaseous emission	*H*	Measured.	% (mass or volume)	
16	Condensed water flowrate in the HPCE	$\dot{m}_{Water\_cond}$	Measured by a sensor.	l/h – l/s kg/h – kg/s	
17	Humidity reduction with iWAYS	H_{red}	$\frac{H_{before\_iWAYS} - H_{iWAYS}}{H_{before\_iWAYS}} * 100$	%	This formula calculates the difference between the humidity of the exhaust before iWAYS (experimental campaign as reference) and the humidity of the exhaust after the iWAYS system installation.
18	Combustion gases	Comb_gases	Measured (sensor)	g/h	The combustion gases to be monitored are: CO, NOx, SO2
19	Dust	Dust	Measured (Sensor)	Concentration (mg/Nm3)	

20	Dust reduction	Dust_red	$\frac{Dust_{before\_iWAYS} - Dust_{iWAYS}}{Dust_{before\_iWAYS}} * 100$	%	
21	Water flowrate recovered from other sources	$\dot{m}_{Water,stream1}$	Measured (sensor) / or calculated as difference from KPI 20 and KPI 16	l/h – l/s kg/h – kg/s	
22	Water flowrate recovered and flowing in the iWAYS treatment system	$\dot{m}_{Water,iWAYS_{IN}}$	Measured (sensor)	l/h – l/s kg/h – kg/s	
23	Water flowrate recycled exiting from the iWAYS system	$\dot{m}_{Water,iWAYS\_OUT}$	Measured (sensor)	/h – l/s kg/h – kg/s	
24	Water recovery efficiency	$Eff_{water\_recovery}$	$\frac{\dot{m}_{Water,iWAYS\_OUT}}{\dot{m}_{Water,iWAYS_{IN}}} * 100$	%	
25	Water saved with iWAYS system	Sav_water	$\int_0^{hp,a} \dot{m}_{Water,iWAYS\_OUT}\, dt$	l/ reporting period (month?)	Saved water according to the iWAYS technology.
26	Potential of hydrogen	Ph	Measured (sensor)		
27	Electrical Conductivity of iWAYS inlet water	$El\_con_{iWAYS\_water}$	Measured (sensor)	µS/cm	
27	Electrical Conductivity of NF Permeate water	$El\_con_{permeate}$	Measured (sensor)	µS/cm	
28	Electric energy consumption of the BOP components of the water treatment system	$E_{en\_BOP\_WaterRec}$	$\int_0^{hp,a} (P_{el\_BOP\_SKID1} + \cdots + P_{el_{BOP\_SKID_2}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS water treatment system (ultrafiltration, nanofiltration, pumps, valves…)

The iWAYS economic KPIs will remain the same as the one reported in the previous table (Section 3.1).

- Alufluor

The specific KPIs for Alufluor will include:

Table 4 – Alufluor Specific KPIs.

iWAYS technology performance KPIs					
	Common Kpi's	***Descriptive name***	***Formula***	***Units***	***Notes***
1	Primary stream (waste source) thermal power recovered	$\dot{Q}_{WH}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{WH,HPCE,out})$	kW	Thermal power recovered from the waste heat source.
2	Primary stream (waste source) available thermal power	$\dot{Q}_{WH\_available}$	$\dot{m}_{WH,HPCE} * cp_{WH} * (T_{WH,HPCE,in} - T_{amb})$	kW	Thermal power available in the exhaust gases
3	Efficiency of the heat recovery	Eff_{rec_heat}	$\frac{\dot{Q}_{WH}}{\dot{Q}_{\_WH\_available}} * 100$	%	Percentage of the recovered thermal power on the available power
4	Thermal power recovered by the secondary stream (thermal fluid)	$\dot{Q}_{SS\_rec}$	$\dot{m}_{SS,HPCE} * cp_{SS} * (T_{SS,HPCE,in} - T_{SS,HPCE,out})$	kW	Thermal power recovered by the thermal fluid in the condenser section of the HPCE
4	Thermal power exploited in the heat sinks. Saved thermal power.	$\dot{Q}_{exp,HS}$	$\dot{m}_{HS\#1} * cp_{thermalflui} * (T_{HS\#1,in} - T_{HS\#1,out}) + \ldots + \dot{m}_{HS\#N} * cp_{thermalfluid} * (T_{HS\#N,in} - T_{HS\#N,out})$	kW	Thermal power exploited in the heat sinks
5	Secondary stream recovered energy (thermal fluid).	$Q_{SS,rec}$	$\int_0^{hp,a} \dot{Q}_{SS,rec} dt$	MWh/reporting period (month?)	Thermal energy recovered in secondary stream of the HPCE. It derives from the KPI Nr.3 and the operating hours of the HPCE.
6	Thermal energy exploited in the heat sinks. Saved thermal energy.	$Q_{exp,HS}$	$\int_0^{hp,a} \dot{Q}_{exp,HS} dt$	MWh/reporting period (month?)	Thermal energy exploited in the heat sinks. It derives from the KPI Nr.4 and the operating hours of the heat sink(s).

7	Efficiency of the heat exploitation system	Eff_{expl_syst}	$\frac{\dot{Q}_{exp,HS}}{\dot{Q}_{SS\_rec}} * 100$	%	Efficiency of the heat exploitation. Thermal power exploited with the respect to the thermal power recovered.
8	Electric energy consumption of the BOP components of the heat recovery section.	$E_{en\_BOP\_HeatRec}$	$\int_0^{hp,a} (P_{el\_BOP\_fan} + \cdots + P_{el_{BOP_{pump}}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS system heat recovery section (fan, valves, pumps…)
9	Fuel consumption mass flow rate without iWAYS	$\dot{m}_{fuel}$	*Measured*	kg/s or Nm3/h	Natural gas consumption in the target process
10	Fuel consumption mass flow rate with iWAYS	$\dot{m}_{fuel\_iWAYS}$	*Measured*	kg/s or Nm3/h	Natural gas consumption in the target process
11	Fuel flowrate Saved with iWAYS	$\dot{m}_{fuel\_saved}$	Method 1: $\dot{m}_{fuel}$ - $\dot{m}_{fuel\_iWAYS}$ (if KPIs 11 -12 are available) Method 2: $\frac{\dot{Q}_{exp,HS}}{LHV\_fuel}$	kg/s	The saved fuel can be calculated from the KPI Nr.4 and the lower heating value of the fuel.
12	Fuel saved over the reporting period	Sav_fuel	$\int_0^{hp,a} \dot{m}_{fuel\_saved} dt$	kg/reporting period (month??)	
13	Total carbon dioxide saved	Sav_CO_2	$Sav\_fuel * coeff_{CO_2}$	t/reporting period	
14	Humidity of the gaseous emission	H	Measured.	% (mass or volume)	
15	Condensed water flowrate in the HPCE	$\dot{m}_{Water\_cond}$	Measured. Since the quantity of the condensed water will be pretty smaller than the total recoverecd water, the idea is to measure it with a transparent system.	l/h – l/s kg/h – kg/s	
16	Humidity reduction with iWAYS	H_{red}	$\frac{H_{before\_iWAYS} - H_{iWAYS}}{H_{before\_iWAYS}} * 100$	%	This formula calculates the difference between the humidity of the exhaust before iWAYS (experimental campaign as reference) and the humidity of the exhaust

					after the iWAYS system installation.
17	Hydrofluoric acid	HF	Measured (sensor)	g/h	
18	Water flowrate recovered and flowing in the iWAYS treatment system	$\dot{m}_{Water,iWAYS_{IN}}$	Measured (sensor)	l/h – l/s kg/h – kg/s	
19	Water flowrate recycled exiting from the iWAYS system	$\dot{m}_{Water,iWAYS\_OUT}$	Measured (sensor)	/h – l/s kg/h – kg/s	
20	Water recovery efficiency	$Eff_{water\_recovery}$	$\frac{\dot{m}_{Water,iWAYS\_OUT}}{\dot{m}_{Water,iWAYS_{IN}}} * 10$ 0	%	
21	Water saved with iWAYS system	Sav_water	$\int_0^{hp,a} \dot{m}_{Water,iWAYS\_OUT}$	l/ reporting period (month?)	Saved water according to the iWAYS technology.
22	Turbidity of iWAYS inlet water	$TUR_{iWAYS\_water\_IN}$	Measured (sensor)	NTU - mg/l	
23	Turbidity of iWAYS Outlet water	$TUR_{iWAYS\_water\_OUT}$	Measured (sensor)	NTU - mg/l	
24	Calcium Hardness of iWAYS inlet water	$HCa_{iWAYS\_water\_IN\_}$	Measured (sensor)	°F - mg/l	
25	Calcium Hardness of iWAYS outlet water	$HCa_{iWAYS\_water\_OUT\_}$	Measured (sensor)	°F - mg/l	
26	Electric energy consumption of the BOP components of the water treatment system	$E_{en\_BOP\_WaterRec}$	$\int_0^{hp,a} (P_{el\_BOP\_SKID1} + \cdots + P_{el_{BOP\_SKID_2}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS water treatment system (ultrafiltration, nanofiltration, pumps, valves…)

The iWAYS economic KPIs will remain the same as the one reported in the previous table (Section 3.1).

- Tubacex

The Tubacex specific KPIs will include:

Table 5 – Tubacex Specific KPIs.

iWAYS technology performance KPIs					
	Common Kpi's	***Descriptive name***	***Formula***	***Units***	***Notes***
1	Thermal power recovered by the secondary stream (thermal fluid)	$\dot{Q}_{SS\_rec}$	$\dot{m}_{SS,HPCE} * cp_{SS} * (T_{SS,HPCE,in} - T_{SS,HPCE,out})$	kW	Thermal power recovered by the thermal fluid in the condenser section of the HPCE
2	Thermal power exploited in the heat sinks. Saved thermal power.	$\dot{Q}_{exp,HS}$	$\dot{m}_{HS\#1} * cp_{thermalfluid} * (T_{HS\#1,in} - T_{HS\#1,out}) + \ldots + \dot{m}_{HS\#N} * cp_{thermalfluid} * (T_{HS\#N,in} - T_{HS\#N,out})$	kW	Thermal power exploited in the heat sinks
3	Secondary stream recovered energy (thermal fluid).	$Q_{SS,rec}$	$\int_0^{hp,a} \dot{Q}_{SS,rec} dt$	MWh/reporting period (month?)	Thermal energy recovered in secondary stream of the HPCE. It derives from the KPI Nr.3 and the operating hours of the HPCE.
4	Thermal energy exploited in the heat sinks. Saved thermal energy.	$Q_{exp,HS}$	$\int_0^{hp,a} \dot{Q}_{exp,HS} dt$	MWh/reporting period (month?)	Thermal energy exploited in the heat sinks. It derives from the KPI Nr.4 and the operating hours of the heat sink(s).
5	Efficiency of the heat exploitation system	Eff_{expl_syst}	$\frac{\dot{Q}_{exp,HS}}{\dot{Q}_{SS\_rec}} * 100$	%	Efficiency of the heat exploitation. Thermal power exploited

					with the respect to the thermal power recovered.
6	Electric energy consumption of the BOP components of the heat recovery section.	$E_{en\_BOP\_HeatRec}$	$\int_0^{hp,a} (P_{el\_BOP\_fan} + \cdots + P_{el_{BOP_{pump}}})\, dt$	kWh/reporting period (month?)	Electric energy consumption of the auxiliary components installed for the functioning of the iWAYS system heat recovery section (fan, valves, pumps…)
7	Fuel consumption mass flow rate without iWAYS	$\dot{m}_{fuel}$	*Measured*	kg/s or Nm3/h	Natural gas consumption in the target process
8	Fuel consumption mass flow rate with iWAYS	$\dot{m}_{fuel\_iWAYS}$	*Measured*	kg/s or Nm3/h	Natural gas consumption in the target process
9	Fuel flowrate Saved with iWAYS	$\dot{m}_{fuel\_saved}$	Method 1: $\dot{m}_{fuel}$ - $\dot{m}_{fuel\_iWAYS}$ (if KPIs 11 -12 are available) Method 2: $\frac{\dot{Q}_{exp,HS}}{LHV\_fuel}$	kg/s	The saved fuel can be calculated from the KPI Nr.4 and the lower heating value of the fuel.
10	Fuel saved over the reporting period	*Sav_fuel*	$\int_0^{hp,a} \dot{m}_{fuel\_saved} dt$	kg/reporting period (month??)	
11	Total carbon dioxide saved	Sav_CO_2	$Sav\_fuel * coeff_{CO_2}$	t/reporting period	
12	Water flowrate recovered from other sources	$\dot{m}_{Water,stream1}$	Measured (sensor) / or calculated as difference from KPI 20 and KPI 16	l/h – l/s kg/h – kg/s	
13	Water flowrate recovered	$\dot{m}_{Water,iWAYS_{IN}}$	Measured (sensor)	l/h – l/s kg/h – kg/s	

	and flowing in the iWAYS treatment system				
14	Water flowrate recycled exiting from the iWAYS system	$\dot{m}_{Water,iWAYS\_OUT}$	Measured (sensor)	/h – l/s kg/h – kg/s	
15	Water recovery efficiency	$Eff_{water\_recovery}$	$\frac{\dot{m}_{Water,iWAYS\_OUT}}{\dot{m}_{Water,iWAYS_{IN}}} * 100$	%	
16	Water saved with iWAYS system	Sav_water	$\int_0^{hp,a} \dot{m}_{Water,iWAYS\_OUT}\, dt$	l/ reporting period (month?)	Saved water according to the iWAYS technology.
17	Temperature of inlet water	T_{iWAYS_inlet}	Measured (sensor)	°C	
18	Temperature of outlet water	T_{iWAYS_outlet}	Measured (sensor)	°C	
19	pH of iWAYS of inlet water	$pH\_{iWAYS\_water\_IN}$	Measured (sensor)		
20	pH of iWAYS of outlet water	$pH\_{iWAYS\_water\_OUT}$	Measured (sensor)		
21	Electrical Conductivity of iWAYS inlet water	$El\_con_{iWAYS\_water\_IN}$	Measured (sensor)	µS/cm	
22	Electrical Conductivity of iWAYS outlet water	$El\_con_{WAYS\_water\_OUT}$	Measured (sensor)	µS/cm	
23	Turbidity of iWAYS inlet water	$TUR_{iWAYS\_water\_IN}$	Measured (sensor)	NTU - mg/l	
24	Turbidity of iWAYS Outlet water	$TUR_{iWAYS\_water\_OUT}$	Measured (sensor)	NTU - mg/l	
25	CO2 contained in water	CO_2_water	Measured (sensor)		
26	Chemical oxygen demand (COD) of iWAYS inlet water	$COD_{iWAYS\_water\_IN}$	Measured (sensor)	g/l	
27	Chemical oxygen demand (COD) of	$COD_{iWAYS\_water\_OUT}$	Measured (sensor)	g/l	

	iWAYS outlet water				
28	Dissolved chromium of iWAYS inlet water	$Cr_{iWAYS\_water\_IN}$		µg/L	
29	Dissolved chromium of iWAYS outlet water	$Cr_{iWAYS\_water\_IN}$		µg/L	
30	Non-ionic surfactant concentration of iWAYS inlet water	$SURF_{iWAYS\_water\_IN}$		mg/L	
31	Non-ionic surfactant concentration of iWAYS outlet water	$SURF_{iWAYS\_water\_IN}$		mg/L	

The iWAYS economic KPIs will remain the same as the one reported in the previous table (Section 3.1).