ETEKINA
Thermal energy recovery

D2.4 – Common validation methodology report (PU)

July 2019

WP 2, T 2.4

Authors: Bakartxo Egilegor, Matteo Venturelli, Fouad Al-Mansour, Marko Peckaj, Sulaiman Almahmoud, Lujean Ahmad and Hussam Jouhara.

Heat pipE TECHnologies for INdustrial Applications.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 768772.

Technical References

Project Acronym	ETEKINA
Project Title	Heat pipE TECHnologies for INdustrial Applications
Project Coordinator	Bakartxo Egilegor Ezenarro Ikerlan S. Coop. (IK4-IKERLAN) Email: begilegor@ikerlan.es
Project Duration	October 2017 – September 2021 (48 months)

Deliverable No.	D11
Dissemination level [1]	PU
Work Package	WP 2
Task	T2.4
Lead beneficiary	IK4-IKERLAN
Contributing beneficiary(ies)	JSI,UMR, BUL
Due date of deliverable	30/09/2018
Actual submission date	24/07/2019

[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)

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Document history			
V	Date	Beneficiary	Author
0.0	03/08/2018	IK4-IKERLAN	Bakartxo Egilegor. Preliminary draft version extracted from D2.3
0.1	11/09/2018	IK4-IKERLAN	Feedback received from of Matteo Venturelli (UMR) and Fouad Al-Mansour (JSI) included in the document. No additional comments from BUL. Corrections in conversion factors of Demo case 1
0.1	1/10/2018	IK4-IKERLAN	Some minor editing changes have been made
1.0	15/07/2019	IKERLAN	The following sentence has been included (page 4): ***This document reflects only the ETEKINA authors views and the European Union is not liable for any use that may be made of the information contained therein*** Descriptive paragraph of the KPIs relevant to adopting HPHE technologies as approach to WHR has been added (page 10)

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Summary

This document compiles a description of the target aspects that are going to be evaluated within ETEKINA 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 ETEKINA project that will be monitored are: sensible energy recovered ratio, primary energy savings, the reduction of greenhouse gas emissions and the reduction of energy cost triggered by the project.
However, as steel, aluminium 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 3 demo cases to evaluate the ETEKINA heat recovery performance in a common way. In this document to preserve the confidentiality the common KPIs are shown.

Defined KPIs are the values to monitor the target impacts defined in the ETEKINA proposal and they will be directly obtained based on measurements of the project before and after the WHRS (Waste Heat Recovery System) installation will be commissioned. Calculating the difference of the KPIs values before and after the installation the target impact values will be verified. The energy saving opportunity given by the heat recovery based on HPHE (Heat Pipe Heat Exchanger) technology defined in ETEKINA project will be evaluated.

The methodology and KPIs described in this document will be used in WP4 for the 3 use cases' installations validation.

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Introduction

The aim of this document is to describe the target aspects that are going to be evaluated within ETEKINA project; the methodology of evaluation and the definition of common key performance indicators (KPIs) to monitor those aspects.
In the first chapter the main impacts of the ETEKINA 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 ETEKINA project impact are described in chapter 2.
The description of the common KPIs to evaluate the ETEKINA heat recovery performance in a common way in the 3 demo cases are described in chapter 3. Defined KPIs are the values to monitor the target impacts defined in the ETEKINA proposal and they will be directly obtained based on measurements of the project before and after the WHRS installation will be commissioned. Calculating the difference of the KPIs values before and after the installation the target impact values will be verified. The energy saving opportunity given by the heat recovery based on HPHE (Heat Pipe Heat Exchanger) technology defined in ETEKINA project will be evaluated.

The methodology and KPIs described in this document will be used in WP4 for the 3 use cases installations validation.

1. Target aspects to evaluate

For estimating ETEKINA 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 ETEKINA project and to establish the expected project impacts.
Within the scope of ETEKINA project the objectives are the following ones:

- To design and develop a heat pipe-based heat exchanger (HPHE) technology and demonstrate its cost-effective waste heat recovery in industrial applications from the non-ferrous, steel and ceramic sectors.
- Recovery of at least 40% of sensible heat contained in each waste heat carrier addressed by the ETEKINA Project
- To reduce in 623 MWh/y, in 2611 MWh/y and in 4500 MWh/y the primary energy use in the processes where heat will be recovered in each demo case, non-ferrous, steel and ceramic respectively.
- To reduce the CO2 emissions by 129 tCO2e/y, by 520 tCO2e /y and by 920 tCO2e /y in

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each demo case, non-ferrous, steel and ceramic cases respectively.

- The waste heat recovery system investment will have a payback period less than 3 years for the three demo cases.
- The improvement of the energy efficiency and the reduction of energy cost will lead to a demonstrated advancement in competitiveness by the end of the project.

Based on those objectives the project performance indicators that will be used in ETEKINA project have been defined and they are shown in Table 1. Those four 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.

Table 1-Etekina project performance indicators

Project Performance Indicator	Quantification		Measurement unit
Sensible energy recovered ratio	>40		%
Primary energy savings triggered by the project	DC1 DC2 DC3	623 2611 4500	MWh/y
Reduction of greenhouse gas emissions	DC1 DC2 DC3	129 520 920	tCO2e /y
Reduction of energy cost triggered by the project	DC1 DC2 DC3	16 65 140	k€/y

2. Common validation methodology

2.1 Energy efficiency standards review

There are different and complementary approaches to certify and to identify energy efficiency improvements:

- ISO 50001 standards family that focuses on establishing an energy management system in an organization to identify energy saving opportunities.
- EN 16247 standards family that focuses on energy audits in different statements (buildings, transport, processes, etc.) to identify energy saving opportunities.

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- ISO1400 standards family that focuses on establishing an environmental management system in an organization.

Two of them (ISO 50006:2014 and EN 16247-3:2014 Energy audits - Part 3: Processes) have been analyzed to find references in the definition of the energy performance indicators for ETEKINA project impact evaluation.

Similarly of ISO 50006, relevant aspects and boundary conditions that influence the processes where the recovery heat is going to be used have been considered in the specific KPIs definition of each demo case. The main KPIs of ETEKINA project and their target values indicated in chapter 1 (equivalently to the EnPIs, Energy Performance Indicators, values defined in the ISO 50006) will be evaluated before and after the WHRS installation will be commissioned (equivalently to the EnBSs, Energy Baselines, reference values of the ISO 50006). Calculating the difference of the values before and after the installation the target values will be verified. The energy saving opportunity defined in ETEKINA project, the heat recovery based on HPHE (Heat Pipe Heat Exchanger) technology, will be evaluated.

The ideas of indicating the accuracy of the measurements and if the evaluated KPIs are measured, estimated or calculated data have been taken from *EN 16247-3:2014 Energy audits - Part 3: Processes* standard.

In *ANNEX 2: Energy related standards* there is a description of the main characteristics of the standards that have been found helpful for the evaluation methodology definition.

2.2 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 ETEKINA 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 the waste heat carrier 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. However, those specific KPIs included some common KPI described in chapter 3.1 to evaluate the three demo cases of the project in an equivalent common way.

The first step for the common methodology has been to define a common nomenclature and the units to be used by all the partners described in D2.5 and D2.6; 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. From those specific Key Performance Indicators, the common Key performance indicators have been defined to

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evaluate the impacts of the project.

Those target impacts, described as common KPI-s in chapter 3.1, will be obtained based on direct measures variables installation before and after the WHRS installation. The difference of the values obtained before and after the WHRS installation will provide the saving values obtained due to the ETEKINA development.

The energy consumption and the available waste heat energy values before the WHRS installation will be measured directly to obtain the project baseline reference values in available waste heat energy, primary energy consumption, greenhouse gas emissions and energy cost. Those baseline reference values initially will be considered as they are obtained from the measures without adjustments. In case there are independent variables (e.g. production level, range of products, degree-days, outdoor temperature, moisture content of the products etc.) that could affect energy use and/or energy consumption the baseline reference values could have been normalized for those variables.

Savings = (Baseline Period Energy – Reporting Period Energy)

To quantify the uncertainty of the results the accuracy of each measure will be indicate and uncertainty propagation will be estimated.
The results of the impact real values obtained from each demo case will be reported in the deliverable D4.4 Subproject report: validation report, experiences for non-ferrous sector, for steel sector and for ceramic sector.

3. Definition of common KPIs

3.1 Common KPIs

3.1.1 Period of data evaluation

To avoid the influence of non-routine adjustments or weather influenced variables, usually long-term periods are considered (i.e. one year) to monitor the performance of a variable. There are two periods of times, one prior (baseline period) and after the improvement action has been installed (reporting period) when the energy performance is evaluated and compared.

The monitoring target period is 12 months for both periods: before and after WHRS installation.

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3.1.2 Evaluated Common Key Performance Indicators

The elements that form the WHRS are:

1. The HPHE (Heat Pipe Heat Exchanger)
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 HPHE's secondary stream cannot be directly introduced in the heat sink process and an intermediate carrier stream is used to deliver the heat in the final heat sink 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 WHRS 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 the specific application characteristics. However, the essential elements of the WHRS are the HPHE, the WH process, the HS process and the BOP. Therefore 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 greenhouse gas emissions and the reduction of energy cost triggered by the project given in the Table 1 are based on the performance of those elements. The main variables to follow are:

- The sensible energy recovered from the available waste heat energy.
    a. The available waste heat energy is calculated based on the waste heat carrier stream characteristics at the point where the carrier stream is conducted to the WHRS.
    b. The specific KPIs related to a HPHE system are the duty of the system and the flow rates of the exhaust and secondary stream in addition to the inlet and outlet temperatures of these streams. Hence, the duty of the HPHE can be calculated from the collected measurements. The duty of the HPHE can be compared to the exhaust waste heat proportional to the ambient temperature to evaluate the efficiency of the HPHE as a WHR technology. The effectiveness of the HPHE depends on the temperature difference between the exhaust and heat sink temperatures and the flow rate as well.

- The net energy consumption reduction in the heat sink processes (gas consumption reduction and electricity consumption reduction or increase due to the auxiliary equipment contribution on electricity consumption)

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- The translation of the previous net energy consumption reduction to
    a. to primary energy savings,
    b. to CO2 equivalent emissions reduction and
    c. to cost reduction.

The indicators have been named and formulated as they are show in Table 2.

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Table 2- Common Key performance indicator list

	KPI	Descriptive Name	Formula	Units
Energy Issues				
1	Recovered Sensible Energy Ratio	R_{QHPHE}	Q_{PStN}/Q_{WH} x 100	%
2	Rejected Energy in Primary Stream	Q_{PSt}	$\int(\dot{Q}_{PSt})$ x dt from t= 0 to $Rtim_{HPHE}$	MWh/y
3	Rejected power in Primary Stream	$\dot{Q}_{PSt}$	$\dot{m}_{PSt}$ x Cp_{PSt} x (T_{PSt_In}-T_{PSt_Out})	kW
4	Thermal energy contained in the heat source.	Q_{WH}	$\int(\dot{Q}_{WH})dt$, t from 0 to $Rtim_{WH}$	MWh/y
5	Thermal power contained in the heat source.	$\dot{Q}_{WH}$	$\dot{m}_{WH}$xCP_{WH} x (T_{WH}-T_{IA})	kW
6	Thermal power transfered to Secondary Stream (s)	$\dot{Q}_{SSt1..n}$	$\dot{m}_{SSt1..n}$ x $Cp_{SSt1..n}$ x ($T_{SSt1..n\_In}$-$T_{SSt1..n\_Out}$)	kW
7	Thermal energy transfered to Secondary Stream (s)	$Q_{SSt1..n}$	$\int(\dot{Q}_{SSt1..n})$ x dt from t= 0 to $Rtim_{HPHE}$	MWh/y
8	Primary Stream mass flow rate	$\dot{m}_{PSt}$		kg/s
9	Secondary Stream mass flow rate	$\dot{m}_{SSt}$		kg/s
10	Waste heat carrier mass flow rate	$\dot{m}_{WH}$		kg/s
11	Primary Stream Specific Heat value	Cp_{PSt}		KJ/kg-ºC
12	Secondary Stream (s) Specific Heat value	$Cp_{SSt1..N}$		KJ/kg-ºC
13	Temperature of Primary stream circuit input line	T_{PSt_In}		ºC
14	Temperature of Primary stream circuit output line	T_{PSt_Out}		ºC
15	Temperature of Secondary stream circuit input line	T_{SSt_In}		ºC
16	Temperature of Secondary stream circuit output line	T_{SSt_Out}		ºC
17	Temperature of waste heat stream	T_{WH}		ºC
18	Ambient temperature	T_{IA}		ºC
19	Running time of the process in which the waste heat is generated	$Rtim_{WH}$		h
20	Running time of the waste heat stream going through the HPHE	$Rtim_{HPHE}$		h
21	Running time of the heat sink 1..N process(es) in which the waste heat is reused	$Rtim_{HS1..N}$		h
22	Running time of intermediate HE of the heat sink 1..N	$Rtim_{ISt1..N}$		h
Primary Energy Issues				
23	Primary energy savings due to the thermal energy reduction	PEQ_{HS_saved}	$Q_{HS\_NGsaved}$*Eff_{PENG}	MWh/y
24	Thermal energy savings in heat sink (s)	$Q_{HS1..n\ NGsaved}$	$Q_{HS1..n\_NGPre}$-$Q_{HS1..n\_NGTime}$	MWh/y

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25	Thermal energy consumed in heat sink process	Q_{HS_NG}	$\int(\dot{Q}_{HS\_NG})dt$ t=from 0 to $Rtim_{HS}$	MWh/y
26.1	Thermal power consumed in heat sink process (es) (referred to HHV)	$\dot{Q}_{HS1..n\_NG}$ (HHV)	$\dot{m}_{HS1..n\_NG}$ x HHV	kW
26.2	Thermal power consumed in heat sink process (es) (referred to LHV)	$\dot{Q}_{HS1..n\_NG}$(LHV)	$\dot{m}_{HS1..n\_NG}$ x LHV	kW
27	Primary energy efficiency Natural gas	Eff_{PENG}		-
Environmental Issues				
28	CO2 savings in heat sink due to Natural gas consumption reduction	$m_{CO2NGHSsaved}$	$Q_{HS\_NGsaved}$*$ConvF_{NG}$	tCO2e/y
29	CO2 conversion factor for Natural gas	$ConvF_{NG}$		tCO2e/MWh
Competitiveness Issues				
30	Reduction of the cost triggered by the project	C_{saved}	$EC_{NGsaved}$+$C_{CO2\_emission\_saved}$	€/y
31	Reduction of fuel cost	$EC_{NGsaved}$	$Q_{HS\ NGsaved}$ x EC_{NG}	€/y
32	CO2 cost saving	$C_{CO2\_emission\_saved}$	$m_{CO2saved}$ x $C_{CO2\_emission}$	€/y
33	CO2 emission cost	$C_{CO2\_emission}$		€/tCO2e
34	Natural gas cost	EC_{NG}		€/MWh

Those indicators could have been normalized for relevant variables which affect energy use and/or energy consumption (e.g. production level, range of products, degree-days, outdoor temperature, etc.)

4. Reference baseline Monitoring Variables

In this chapter the required monitoring variables and their accuracy and the reference baseline definition for the performance evaluation of the 3 demo cases are described.

4.1 Reference baseline definition

The reference baseline will be defined based on the current energy consumption measures of the sink processes where the recovered energy is going to be used. Those measures will be done along the precedent months to the WHRS installation.

Based on that consumption, its equivalent primary energy value, corresponding greenhouse gas emissions and energy cost will be evaluated. Those values will constitute the reference baseline to be compared with the values triggered by the project in the heat sinks processes after WHRS

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installation. Those real impact indicators triggered by the project will be evaluated and checked against defined target values.

The following tables will be completed using monthly and yearly consumption data and they will constituted the reference baseline data to be compared with the data collected after the WHRS installation was commissioned.

Table 3 Monthly reference baseline

ETEKINA Demo Case X		Month YYYY	Units
Thermal energy contained in the Heat source	Q_{WH}	value	MWh/month
Rejected energy in the Primary Stream	Q_{PSt}	value	MWh/month
Recovered sensible energy ratio	R_{QHPHE}	**value**	**%**
Monthly Heat Sink process NG consumption (HHV)	Q_{HS_NG}	value	MWh/month
Monthly NG cost	EC_{NG_HS}	value	€/month
CO2 emission cost	$C_{CO2\_emission\_saved}$	value	€/month
Monthly PE consumption	PE_{HS}	**value**	**MWh/month**
Monthly CO2 emissions	m_{CO2_HS}	**value**	**kgCO2/month**
Monthly energy and emissions cost	EC_{HS}	**value**	**€/month**
Eff_{PE_NG}		constant	MWh_PE/MWh
$ConvF_{NG}$		constant	kgCO2/MWh(HHV)
EC_{NG}		constant	€/MWH
$C_{CO2\_emission}$		constant	€/tCO2e

Table 4 Yearly reference baseline

ETEKINA Demo Case X	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018	Units
Q_{WH}	value	value	value	value	value	value	value	value	value	value	value	value	**value**	MWh/y
Q_{PSt}	value	value	value	value	value	value	value	value	value	value	value	value	**value**	MWh/y
R_{QHPHE}	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	value	%
Q_{HS_NG}	value	value	value	value	value	value	value	value	value	value	value	value	**value**	MWh/y
EC_{NG_HS}	value	value	value	value	value	value	value	value	value	value	value	value	**value**	€/y
$C_{CO2\_emission\_saved}$	value	value	value	value	value	value	value	value	value	value	value	value	**value**	€/y
PE_{HS}	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	value	MWh/y
m_{CO2_HS}	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	value	kgCO2/y
EC_{HS}	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	**value**	value	€/y

For Sensible energy recovered ratio a reference baseline definition is not needed because recovery energy only occurs after WHRS is installed and therefore the impact of the energy recovered ratio will be evaluated based on measurements after the WHRS has been installed.

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ANNEX 1: Nomenclature

Variable type	Meaning	Units
p	Pressure	bar, Pa
T	Temperature	°C
Cp	Specific heat capacity	kJ/(kg K)
$\dot{m}$	Mass flow	kg/s
m	Mass consumed	kg/y
Δp	Pressure difference	bar
Q	Thermal energy	MWh/y
$\dot{Q}$	Thermal power	kW
H	Humidity	%
LHV	Lower heating value of a fuel	kJ/kg
Eff	Efficiency	%
δ	Density	kg/m^3
Gr	Granulometry	µm
V	Viscosity	PI
C	Cost	€

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Subscript	Variable referred to
PSt	Primary stream
SSt	Secondary stream
HPHE	Heat Pipe Heat Exchanger
fluid	Thermal fluid
S	Stack
amb	Ambient
dil	Dilution
comb	Combustion
F	Filter
WH	Waste heat
HS	Heat Sink
$h_{p,a}$	Hours of plant activity per year
HS#1	Heat exchanger 1
HS#2	Heat exchanger 2
CH_4	Methane
CO_2	Carbon dioxide
Sav	Saving
$Coeff_{CO2}$	Quantity of CO_2 per kg of CH_4
$Cost_{CO2\_emission}$	Emission CO_2 cost
Opt	Operation time of HPHE per year
NG	Natural gas

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ANNEX 2: Energy related standards

ISO 50001

Developed by ISO technical committee, ISO/TC 242, *Energy management,* the following standards are regarding Energy management:

- ISO 50001:2011 Energy management systems -- Requirements with guidance for use
- ISO 50002:2014 Energy audits -- Requirements with guidance for use.
- ISO 50003:2014 Energy management systems -- Requirements for bodies providing audit and certification of energy management systems.
- ISO 50004:2014 Energy management systems -- Guidance for the implementation, maintenance and improvement of an energy management system.
- ISO 50006:2014 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance.
- ISO 50015:2014 Energy management systems -- Measurement and verification of energy performance of organizations -- General principles and guidance.

EN 16247

This standard describes the audits that need to be performed on energy management schemes. It consists of five parts:

- EN 16247-1:2012 Energy audits — Part 1: General requirements.
- EN 16247-2:2014 Energy audits - Part 2: Buildings.
- EN 16247-3:2014 Energy audits - Part 3: Processes.
- EN 16247-4:2014 Energy audits - Part 4: Transport.
- EN 16247-5:2015 Energy audits - Part 5: Competence of energy auditors.

ISO 14000

ISO 14000 compiles a family of environmental management standards developed by ISO technical committee, ISO/TC 207, *Environmental management.* Regarding to environmental performance evaluation the following ones have been selected:

- ISO 14031:1999 Environmental management – Environmental performance evaluation – Guidelines.
- ISO/TS 14033:2012 Environmental management -- Quantitative environmental information -- Guidelines and examples.
- ISO 14034:2016 Environmental management -- Environmental technology verification (ETV).
- ISO 14064-1:2006 Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.

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- ISO 14064-2:2006 Greenhouse gases – Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.
- ISO 14064-3:2006 Greenhouse gases – Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions.
- ISO 14065:2007 Greenhouse gases – Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition.
- ISO/CD 14066 Greenhouse gases – Competency requirements for greenhouse gas validators and verifiers document.
- ISO/WD 14067-1 Carbon footprint of products – Part 1: Quantification.
- ISO/AWI 14069 GHG – Quantification and reporting of GHG emissions for organizations (Carbon footprint of organization) – Guidance for the application of ISO 14064.

EN 16231:

This standard describes the Energy efficiency benchmarking methodology

The Following Energy Performance Indicator (EPI) is defined

$$EPI = \frac{\sum Energy\ input\ (primary, final\ or\ usable\ energy)}{\sum \text{Main products(products, services or usable energy)}}$$

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References

[1] Guidelines for the calculation of project performance indicators. v2.0 05 December 2017. European Commission. Executive Agency for Small and Medium-sized Enterprises (EASME) Unit B1. https://ec.europa.eu/easme/sites/easme-site/files/guidelines-for-the-calculation-of-performance-indicators.pdf

[2] ISO 50006:2014 Energy management systems -- Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) -- General principles and guidance

[3] EN 16247-3:2014 Energy audits - Part 3: Processes.

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