Report on Key Performance Indicators

Deliverable D3.1

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Abbreviations and acronyms

PU:	Public
WP:	Work package
T:	Task
D:	Deliverable
M:	Month
EU:	European Union
KPIs:	Key performance indicators
IS:	Industrial symbiosis
CE:	Circular economy
CO:	Carbon monoxide
CO_2:	Carbon dioxide
H_2:	Hydrogen
NG:	Natural gas
GHG:	Greenhouse gas
COG:	Coke oven gas
BFG:	Blast furnace gas
BF:	Blast furnace
BOF:	Basic oxygen furnace
EAF:	Electric arc furnace
DRP:	Direct reduction process
LF:	Ladle furnace
TRL:	Technology readiness level

Summary

This deliverable D3.1 entitled “Report on Key Performance Indicators” is prepared within the frame of the Symbio-Steel project as an output of T3.1 “Monitoring of Key Performance Indicators”. It provides the main KPIs that can be used within the IS context in iron and steelmaking and other energy- and CO_2-intensive sectors.

The deliverable also defines the main areas related to the iron and steelmaking process to be monitored and/or calculated/deduced to measure the progress of the IS demonstration activities and analyze the project's main results in later parts of the Symbio-Steel project. This comprises, among other things, funded national, regional, and EU projects and connected best practice solutions.

The objective of this deliverable is to:

(i) provide a starting point for further monitoring relevant actions that the funded national, regional, and EU projects are taking to advance IS.

(ii) establish a scope and definition for selecting indicators relevant to the Symbio-Steel project.

(iii) deliver the list of indicators selected under T3.1 activities.

Consequently, 11 KPIs are defined and proposed for monitoring and reporting the progress of the funded national, regional, and EU projects on IS relevant to the Symbio-Steel project.

1.Introduction

The iron and steelmaking industry is among the most energy-intensive sectors globally, significantly contributing to energy consumption, resource utilization, and emissions[1]. Extensive efforts have been dedicated to optimize resource and energy use to lower its global energy consumption and mitigate its environmental impact[2].

From this perspective, IS[3] offers an alternative approach to accelerate improvements while advancing the industry transition toward greater circularity. It involves industries collaborating to optimize resource and by-product utilization, minimize waste, and enhance overall efficiency by repurposing by-products and sharing resources such as utilities and infrastructure.

In 2018, the European Committee for Standardization established a workshop agreement focused on IS[4], and defined IS as:

> "Industrial symbiosis is the use by one company or sector of underutilized resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment, and materials) from another, with the result of keeping resources in productive use for longer."

KPIs are important tools for measuring the effectiveness of IS in the iron and steelmaking industry and other energy- and CO_2-intensive sectors. IS involves industries collaborating to optimize resource use, reduce waste, and minimize environmental impact. The Symbio-Steel project will collect information from research initiatives dedicated to IS and sector coupling within the funded regional, national, and EU projects. Moreover, by evaluating the environmental-related KPIs (for instance, emission reduction or waste/by-products recycling potentials, etc.), the Symbio-Steel project will contribute to long-term environmental impact reduction.

The content of KPIs definitions related to the Symbio-Steel project has been created according to standards ISO 22400-1:2014(E) and ISO 22400-2:2014(E)[5,6].

The result of this task will be used in several other parts of the Symbio-Steel project. Namely, it will monitor the progress of the funded regional, national, and EU projects (WP3) and identify synergies with other industries (WP4) and policy recommendations (WP5) to achieve an effective industrial rollout of sector coupling technologies, in which the EU steel sector plays a central role.

2.Definitions and scopes of Key Performance Indicators (KPIs)

The definitions presented in Tables 1–11 will be used to calculate or deduce the KPIs. However, more detailed definitions will be required once other activities within the Symbio-Steel project will start applying these KPIs to ensure consistent monitoring. The collected data will include values and specific definitions, equations, and relevant information from regional and EU-funded projects. Depending on the focus of the national, regional, and EU-funded projects, one or more of the 11 defined KPIs will be applied to assess, monitor, and report on the progress of the funded national, regional, and EU projects in implementing IS and relevant to the Symbio-Steel project. This approach will ensure uniformity in KPIs monitoring and provide a clear understanding of how the values are derived.

2.1 Environmental indicators

2.1.1 Key performance indicator: Heat recovered

This KPI reflects how heat recovery systems are integrated into the production process. The recovery of heat from process industries is a well-established practice and is an example of IS, where another repurposes a by-product from one industry. Heat recovery includes capturing waste heat, steam, or by-products such as gases (for instance, COG or BFG) and reusing them for external applications. Sharing excess recovered heat with neighbouring industries can increase the benefits of heat recovery. For instance, waste heat from steel production can supply district heating networks, and by-product gases can be utilized to generate power or fuel for other industrial processes. The ability to recover heat effectively can reduce, for instance, reliance on primary energy inputs.

Table 1. Heat recovered.

KPI definition (I)	
Name	Heat recovered.
Related to the process of iron and steelmaking	This applies to energy-intensive processes in iron and steelmaking, namely iron ore sintering, coke oven, BF, BOF, and EAF.
Description	This KPI measures the proportion of heat recovered and repurposed within an IS. It quantifies heat utilization efficiency, whereas another reuses one industry's by-product (residual heat).
Unit of measure	%
Expected impact	It enhances cost savings, reduces CO_2 emissions, and improves operational efficiency.
Notes	This includes all heat recovered and utilized by other industries in the IS.
	Heat recovery sources may include waste heat from furnaces, off-gases, or process residuals. High recovery rates indicate better energy efficiency and resource utilization.
	Necessary for compliance with environmental regulations related to energy use and emissions.
Formula:	
Share of heat recovered.	$\left(\frac{Recovered\ heat\ reused\ by\ other\ industries}{Total\ residual\ heat\ available}\right) \times 100\%$

2.1.2 Key performance indicator: Direct CO_2 emissions (Scope 1) reduction

Figure 1 shows that Scope 1 (direct emissions) provides opportunities to evaluate the industry's direct CO_2 emissions[8] reduction.

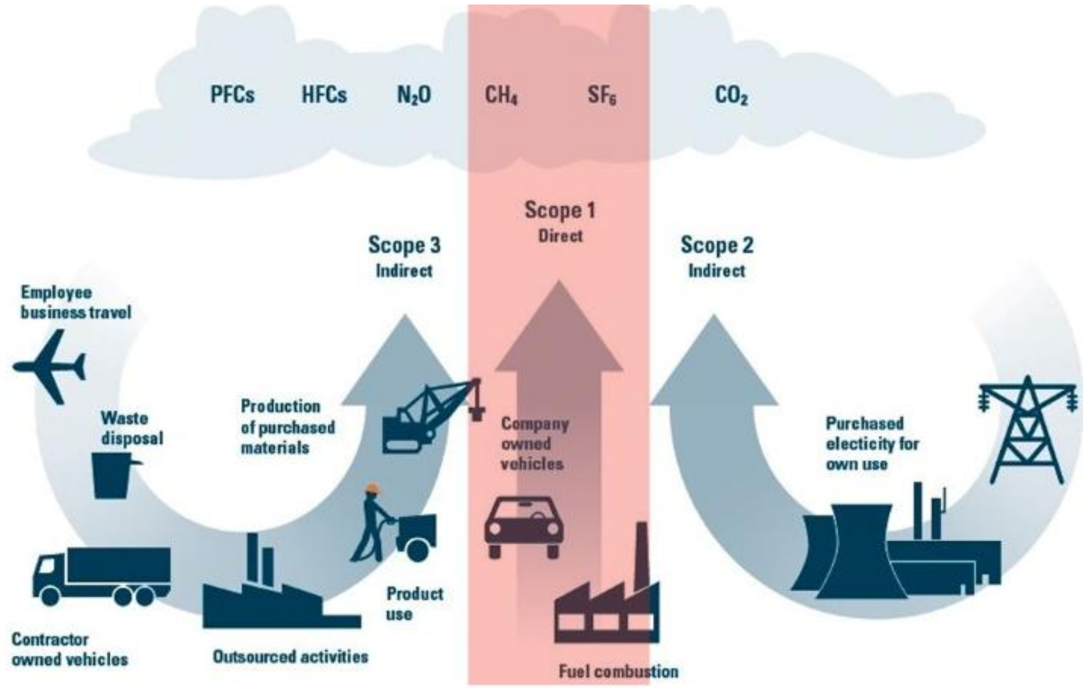

Figure 1. Greenhouse gas emissions associated with industrial processes[9].

Direct-specific CO_2 emissions (Scope 1) refer to CO_2 emissions released directly from the primary production processes and do not include the indirect effects. These emissions result from on-site combustion of fossil fuels, namely coal, coke, NG, or other carbon materials, that produce heat, drive reduction reactions, carburization, and achieve the required temperature conditions in processes like BF. Direct CO_2 emissions are directly correlated to production activities and are influenced by the fuel type, process efficiency, and production volume.

From the IS perspective, this KPI (Table 2) measures the direct CO_2 emissions avoided by one industry due to the reuse of CO_2 provided by another industry. This shows the ecological benefits of CO_2 utilization and collaboration between different industries.

Table 2. Direct CO_2 emissions (Scope 1) reduction.

KPI definition (II)	
Name	Direct CO_2 emissions (Scope 1) reduction.
Related to the process of iron and steelmaking	It can be applied to processes, namely iron ore sintering, pelletizing, cokemaking, the BF-BOF route, DRP, and EAF.
Description	KPI quantifies the reduction in Scope I CO_2 emissions (direct emissions) for industries participating in an IS. Specifically, it measures the direct CO_2 emissions avoided by one industry due to the reuse of CO_2 provided by another industry within the IS. This shows the environmental benefits of CO_2 utilization and collaboration between different industries.
Unit of measure	%
Expected impact	CO_2 emissions reduction.
Notes	Only Scope I emissions reductions resulting directly from one industry's reuse of CO_2, as provided by another industry in the IS, can be considered.
	Indirect emissions (Scope II or III) should not be taken into account.
Formula:	
Scope 1: Direct specific CO_2 emission reduction	$\frac{CO_2\ reused\ by\ one\ of\ the\ industrial\ partners}{Initial\ (Scope\ I) CO_2 emissions} \times 100\%$

2.2 Reduction in virgin raw material usage indicators

2.2.1 Key performance indicator: reduction in virgin raw material usage

Reducing virgin raw material usage KPI (Table 3) focuses on minimizing the extraction and consumption of primary raw materials, such as iron ore, coal, and limestone, by enhancing the utilization of secondary materials, by-products, and waste streams. Such approaches reduce environmental impact and align with the principles of IS, through resource transactions across industries to achieve greater efficiency.

This KPI can be considered generally or can be divided in more detail into components of the sub-KPI. The reduction in virgin raw material usage can be assessed through the following components:

- enhancing the recycling of low-quality steel scrap.

Steel scrap in steelmaking is typically used either in an EAF for scrap-based steelmaking or in a BOF for ore-based steelmaking. Higher post-consumer scrap utilization reduces virgin material demand and significantly lowers CO_2 emissions associated with raw material extraction and processing.

- utilization of by-products and industrial wastes.

By-products from iron and steelmaking and other industries can substitute virgin raw materials. For instance:

i) slag recycling rate.
ii) dust and sludge recovery and reuse.
iii) recycling rate of iron-rich residue streams.
iv) replacement rate of fossil carbon materials.

Table 3. Reduction in virgin raw material usage.

KPI definition (III)	
Name	Reduction in virgin raw material usage.
Related to the process of iron and steelmaking	This applies to processes that conventionally can rely on virgin raw materials such as iron ore, coal, and limestone, namely iron ore sintering, pelletizing, cokemaking, BF, DRP, and EAF. IS practices, namely recycling and using by-products, can reduce virgin raw material consumption.
Description	Evaluate the decrease in virgin raw material usage (iron ore, coal, limestone) resulting from incorporating recycled inputs and IS practices. This KPI reflects efforts to reduce resource dependency and improve material efficiency.
Unit of measure	%
Expected impact	Decreased dependency on virgin raw resources, cost savings, improved environmental situation, reduced mining impacts.
Notes	High reduction rates indicate effective recycling and material efficiency strategies.
	Contributes to resource conservation.
Formula:	
Reduction in virgin raw material usage	$\left(\frac{Virgin\ raw\ material\ reduction\ due\ to\ recycling}{Total\ virgin\ raw\ material\ used\ initially}\right) \times 100\%$

2.2.2 Key performance indicator: enhancing the recycling of low-quality steel scrap

While high-quality steel scrap is readily used in steelmaking, low-quality scrap often presents challenges due to impurities, non-metallic inclusions, and variability in composition. Low-quality steel scrap often contains impurities[10], such as copper, tin, lead, and other tramp elements that affect the quality and properties of finished steel products; non-metallic inclusions, including paint, coatings, and other contaminants, require pre-treatment or additional processing. Additionally, variability in composition complicates process management and product consistency.

Enhancing the recycling of low-quality steel scrap KPI (Table 4) shows the variation in the amount of post-consumer scrap used over a defined period. It assesses the effectiveness of IS in increasing the use of post-consumer scrap. Secondly, it would allow the monitoring of pig iron replacement rate by post-consumer scrap.

Table 4. Enhancing the recycling of low-quality steel scrap.

KPI definition (IV)	
Name	Enhancing the recycling of low-quality steel scrap.
Related to the process of iron and steelmaking	This applies to steel scrap management processes, including pre-treatment, cleaning, and scrap yard management. It is relevant for BOF and EAF, where recycled steel scrap can replace pig iron or virgin steel.
Description	Progressively increasing the usage of low-quality steel scrap grades (post-consumer) into high-quality steel grades.
	Progressively replace the use of pre-consumer grades with post-consumer low-quality steel scrap.
	Replacement of pig iron with post-consumer low-quality steel scrap to reduce reliance on virgin raw resources.
Unit of measure	%
Expected impact	Monitor the progress in the use of post-consumer scrap. Reduced dependency on virgin materials and decreased CO_2 emissions.
Notes	High replacement rates indicate effective recycling and integration of scrap materials.
	Supports reducing mining impacts and energy use associated with virgin iron production.
	Ensures sustainable steel production practices through better scrap utilization.
Formula:	
Change in post-	$\left(\frac{Post-consumer\ scrap\ used\ in\ current\ period - post-consumer\ scrap\ used\ in\ baseline\ period}{Post-sonsumer\ scrap\ used\ in\ baseline\ period}\right) \times 100\%$

consumer scrap use	
Pig iron replacement rate by post-consumer scrap	$\left(\frac{Post - consumer\ scrap\ used\ to\ replace\ pig\ iron}{Total\ pig\ iron\ used\ without\ substitution}\right) \times 100\%$

2.2.3 Key performance indicator: slag recycling rate

The slag recycling rate KPI (Table 5) measures the proportion of repurposed slag generated and used in cement production, construction aggregate, or fertilizer applications[11]. This KPI tracks the effectiveness of slag recycling from BF, BOF, EAF, or LF initiatives and measures resource efficiency in by-product management.

Table 5. Slag recycling rate.

KPI definition (V)	
Name	Slag recycling rate.
Related to the process of iron and steelmaking	This applies to slag generated in iron and steelmaking processes in BF, BOF, EAF, and LF.
Description	The proportion of repurposed slag generated can be used in applications such as cement production, construction aggregate, or fertilizer. This KPI tracks the effectiveness of slag recycling from BF, BOF, EAF, or LF initiatives and measures resource efficiency in by-product management.
Unit of measure	%
Expected impact	Reduces waste, lowers landfill use and cost, promotes CE practices, decreases raw material demand in other industries, and improves sustainability in steel production.
Notes	High recycling rates indicate the effective utilization of slag as a by-product.

	Slag recycling can reduce production costs in related industries by providing alternative raw materials.
	It is important to decrease the environmental and economic impacts of iron and steelmaking by diverting slag from landfills.
Formula:	
Slag recycling rate	$\left(\frac{Slag\ produced\ within\ the\ specific\ process\ (BF, BOF, EAF\ or\ LF)\ sent\ to\ recycling}{Total\ slag\ generated\ within\ the\ specific\ process\ (BF, BOF, EAF\ or\ LF)}\right) \times 100\%$

2.2.4 Key performance indicator: dust and sludge recovery and reuse

The recovery and reuse of dust and sludge KPI (Table 6) represent by-products, often considered waste, that contain valuable materials such as iron, zinc, and other trace elements. Enhancing their recovery and reuse reduces waste disposal and promotes resource efficiency, cost savings, and cross-industry collaboration.

Dust and sludge are generated at various stages of iron and steelmaking production, including coal and coke dusts, BF dust, BOF dust and sludge, EAF dust, rolling mill dust, and sinter plant dust.

Table 6. Dust and sludge recovery and reuse.

KPI definition (VI)	
Name	Dust and sludge recovery and reuse.
Related to the process of iron and steelmaking	This applies to processes in iron and steelmaking that generate dust and sludge, such as cokemaking, iron ore sintering, BF, BOF, and EAF.
Description	This KPI measures the effectiveness of managing dust and sludge generated in the iron and steel production process by assessing reused and recycled fractions. It provides insight into the effectiveness of recycling technologies and waste management strategies, emphasizing reducing reliance on landfills and maximizing the recovery of materials for reuse and recycling in production or other applications[12].

Unit of measure	%
Expected impact	Reduces landfill usage, minimizes environmental contamination, and supports resource efficiency.
Notes	It can also be used in other industrial applications, such as construction materials or as additives in other processes.
	Required for reducing waste.
Formula:	
Fraction of reused/recycled	$\left(\frac{Mass\ of\ reused/recycled\ fraction}{Total\ mass\ of\ dust\ and\ sludge\ generated}\right) \times 100\%$

2.2.5 Key performance indicator: recycling rate of iron-rich residue streams

Recycling rate of iron-rich residue streams KPI (Table 7) focuses on iron-rich residues, such as mill scale, slag, dust, and sludge, which are valuable by-products that contain significant amounts of recoverable iron.

This KPI quantifies the proportion of iron-rich residues (for instance, mill scale, iron ore fines, dust, sludge) recycled and reintegrated into the iron and steelmaking process or other industrial applications.

Table 7. Recycling rate of iron-rich residue streams.

KPI definition (VII)	
Name	Recycling rate of iron-rich residue streams.
Related to the process of iron and steelmaking	Iron-rich residues may come from various metallurgical processes, including BF and steelmaking dust, mill scale, and sludge.
Description	This KPI quantifies the proportion of iron-rich residues (e.g., mill scale, iron ore fines, dust, sludge) recycled and reintegrated into the iron and steelmaking process or other industrial applications.
Unit of measure	%

Expected impact	Recovering valuable iron content, reducing reliance on virgin iron ore. Reintegrating iron-rich residue into the production cycle.	
Notes	Recycling methods can include direct reuse in iron ore sintering or BF or as raw materials in other industries (for instance, cement).	
	Monitoring the KPI allows tracking progress in optimizing material efficiency.	
Formula:		
Recycling rate	$\left(\frac{Mass\ of\ recycled\ iron - rich\ residues}{Total\ mass\ of\ iron - rich\ residues\ generated}\right) \times 100\%$	

2.2.6 Key performance indicator: replacement rate of fossil carbon materials

The replacement rate of fossil carbon materials KPI (Table 8) focuses on the full or partial replacement of fossil carbon materials such as coal, coke, and NG that act in iron and steelmaking (depending on the type of carbon material) as fuel, reducing agent, keeping the burden structure, along with sustaining skeleton permeability and drainage efficiency, act as a filter for soot and dust. As a carbon source, they contribute to processes like carburization and chemical energy supply and are a source for obtaining reducing gases and chemicals. Replacing these fossil carbon materials inputs with alternative, fully or partially renewable, or recycled sources can significantly lower CO_2 emissions and promote resource efficiency. In the context of IS, collaboration with other industries enables the sourcing and repurposing of alternative carbon materials.

To enhance the replacement rate, the following carbon alternatives can be integrated into iron and steel production processes:

- Biomass, raw or after mechanical treatment, heat treatment (or can be applied both), biocoke can partially or fully replace coal or coke in iron ore sintering, iron ore pelletizing, BF, and EAF. This utilization can be further explained by biomass being considered CO_2-neutral. Therefore, the CO_2 from solid products of biomass heat treatment does not contribute to GHG increase when used in thermal processes.

- Waste plastics that cannot be recycled mechanically can be used as reducing agents or supplemental fuel, reducing agents in BF and substituting coal and coke. Additionally, they can be considered a carbon source for EAF. Waste plastics offer a dual benefit by reducing fossil carbon material usage and diverting materials from landfills.
- Industrial by-products that are carbon-rich residues from other industries, for instance, coal and coke dusts in cokemaking, petrochemical waste, refinery by-products, and methane cracking, can serve as carbon sources, replacing conventional fossil carbon material inputs.

Table 8. Replacement rate of fossil carbon materials.

KPI definition (VIII)	
Name	Replacement rate of fossil carbon materials.
Related to the process of iron and steelmaking	This applies to processes usually using fossil carbon sources, such as cokemaking, iron ore sintering, pelletizing, BF, and EAF, where alternative carbon materials can be introduced.
Description	Measures the extent to which fossil carbon materials, e.g., coal and coke, are replaced with alternative or renewable carbon materials in a specific industrial process. This KPI indicates progress toward reducing reliance on fossil fuels using biomass, raw or after mechanical treatment, heat treatment, biocoke, or recycled carbon sources, such as polymers.
Unit of measure	%
Expected impact	Reduced fossil fuel dependency and alignment with CO_2 emissions reduction.

Notes	High replacement rates suggest an effective transition to renewable or recycled carbon sources.
	Replacement sources include biomass, biochar, or other carbon-neutral/recycled carbon materials (e.g., polymers).
Formula:	
Replacement rate of fossil carbon materials	$\left(\frac{Amount\ of\ alternative\ carbon\ used}{Total\ carbon\ materials\ used}\right) \times 100\%$

2.3 Key performance indicator: CO_2 from off-gases reuse

CO_2 from off-gases reuse KPI[13] reflects the reduction of carbon emissions. Capturing CO_2 from high-volume process emissions, for instance, BF mitigates GHG and allows for cross-industry collaboration[14] through IS. Additionally, IS enhances the value of captured CO_2 by fostering partnerships between iron and steelmaking and other industries, for instance, energy and cement. Moreover, captured CO_2 can be used as a raw material for producing chemicals, such as methanol, urea, and carbonates, or combined with hydrogen to produce fuels like methane or methanol, supporting the energy transition. Additionally, cooperating with construction industries to use CO_2 in producing carbonated concrete or aggregates.

CO_2 from off-gases reuse rate KPI (Table 9) measures the amount of CO_2 captured by one industry and reused from off-gases by another industry. It reflects the efficiency of utilizing CO_2 from off-gases as a resource.

Table 9. CO_2 from off-gases reuse.

KPI definition (IX)	
Name	CO_2 from off-gases reuse.
Related to the process of iron and steelmaking	Processes that generate CO_2 emissions, such as cokemaking, iron ore sintering, BF, DRP, and EAF, and steel mill internal power plants, where off-gases can be captured for CO_2 reduction.
Description	Includes CO_2 recovered from industrial off-gases (e.g., flue gases, process emissions) and reused by another partner.
	Indicates the efficiency of CO_2 reuse.
Unit of measure	%
Expected impact	Reduction in CO_2 emissions.
Notes	Higher values indicate greater utilization of CO_2 from off-gases.
	Demonstrates the effectiveness of CO_2 utilization strategies.
	Supports collaboration between industries to optimize CO_2 usage.
Formula:	
CO_2 from off-gases reuse rate	$\left(\frac{Reused\ CO_2\ from\ off-gases}{Total\ CO_2\ emissions\ from\ off-gases}\right) \times 100\%$

2.4 Key performance indicator: share of carbon content in process gas (CO_2/CO) transformed into products

Share of carbon content in process gas (CO_2/CO) transformed into products KPI[13] (Table 10) measures the proportion of carbon content in process gases (CO_2/CO) that is captured and repurposed onto value-added products. This KPI tracks the effectiveness of CO_2/CO capture and utilization efforts, indicating progress toward reducing CO_2 emissions and enhancing resource efficiency.

Table 10. Share of carbon content in process gas (CO_2/CO) transformed into products.

KPI definition (X)	
Name	Share of carbon content in process gas (CO_2/CO) transformed into products.
Related to the process of iron and steelmaking	This applies to processes that generate CO_2/CO as off-gases, for instance, BF and smelting reduction, where carbon capture and utilization are possible.
Description	Measures the proportion of carbon content in process gases (CO_2/CO) that is captured and repurposed onto value-added products. This KPI tracks the effectiveness of CO_2/CO capture and utilization efforts, indicating progress toward reducing CO_2 emissions and enhancing resource efficiency.
Unit of measure	%
Expected impact	Reduced CO_2 emissions and enhanced resource efficiency contributed to CE objectives.
Notes	High transformation rates indicate effective utilization of captured CO_2/CO.
	It allows for the minimization of waste and the conversion of CO_2 emissions into useful products.
Formula:	
Share of carbon content in process gas (CO_2/CO) transformed into products	$\left(\frac{Carbon\ content\ in\ \frac{CO}{CO_2}\ used\ for\ products}{Total\ carbon\ content\ in\ \frac{CO}{CO_2}\ in\ process\ gas}\right) \times 100\%$

2.5 Key performance indicator: technology readiness level

Technology readiness level (TRL)[15] KPI (Table 11) assesses the maturity of technologies being developed, from initial concept (TRL

1) through to full operational use in a real-world environment (TRL 9) or deployment in the iron and steelmaking industry.

Table 11. Technology readiness level.

KPI definition (XI)	
Name	Technology readiness level.
Related to the process of iron and steelmaking	This applies to innovative technologies aimed at improving iron and steelmaking processes, such as emissions reduction technologies, energy efficiency measures, carbon capture, or new production methods.
Description	Measures the maturity of a technology, from initial concept (TRL 1) through to full operational use in a real-world environment (TRL 9). Indicates how close a technology is to deployment and operational integration.
Unit of measure	TRL scale.
Expected impact	Enables evaluation of new technologies progress. High TRL levels indicate readiness for implementation.
Notes	Regular assessments allow tracking of technology development and maturity over time.
	High TRL levels facilitate faster technology adoption, contributing to enhanced efficiency.
	TRL scores are based on established guidelines, ensuring a standardized measure of technology maturity.
Formula:	
Technology readiness level	Regular assessments are needed to determine their current TRL level for the projects where it is possible to apply.

In the context of IS, TRL reflects the progress of innovations aimed at optimizing resource sharing, energy efficiency, and emissions reduction through industry collaboration.

3.Conclusions

This deliverable defines and lists KPIs related to IS within the context of the Symbio-Steel project, supporting the monitoring of funded regional and EU projects. For the Symbio-Steel project, the proposed KPIs are intended for use in specific project activities and are accompanied by detailed indicator definitions to conduct their application.

The list of defined KPIs can be summarised as follows:

	List of KPIs related to the Symbio-Steel project
KPI I	Energy efficiency
KPI II	Direct CO_2 emissions (Scope 1) reduction
KPI III	Reduction in virgin raw material usage
KPI IV	Enhancing the recycling of low-quality steel scrap
KPI V	Slag recycling rate
KPI VI	Dust and sludge recovery and reuse
KPI VII	Recycling rate of iron-rich residue streams
KPI VIII	Replacement rate of fossil carbon materials
KPI IX	CO_2 capture rate from process/off-gasses
KPI X	Share of carbon content in process gas (CO_2/CO) transformed into products
KPI XI	Technology readiness level

Within environmental indicators, heat recovered KPI measures the proportion of heat recovered and repurposed within an IS. It quantifies heat utilization efficiency, whereas another reuses one industry's by-product (residual heat).

Additionally, the CO_2 emissions reduction KPI provides opportunities to evaluate the industry's emissions reduction within Scope 1 (direct emissions).

Reduction in virgin raw material usage has been considered a standalone KPI that focuses on minimizing the extraction and use of primary raw materials like iron ore, coal, and limestone by increasing the use of secondary and recycled materials or dividing into sub-KPIs.

- Enhancing the recycling of low-quality steel scrap KPI addresses the effectiveness of IS in increasing the use of post-consumer scrap. Secondly, it would allow the monitoring of pig iron replacement rate by post-consumer scrap.
- The slag recycling rate KPI focuses on the proportion of slag repurposed for applications like cement production, construction materials, or fertilizer. This KPI shows the effectiveness of slag recycling actions. High recycling rates indicate the effective integration of IS practices and resource efficiency.
- Dust and sludge recovery and reuse KPI will monitor the efficiency of recovering valuable materials.
- Recycling rate of iron-rich residue streams KPI focuses on maximizing the recovery of iron-rich residues, such as mill scale, dust, and sludge, for reuse in steelmaking or other industrial applications. By improving recycling rates, this KPI can monitor improvement toward material efficiency and reduce the need for virgin iron ore.
- The replacement rate of fossil carbon materials with alternatives like biomass, torrefied biomass, charcoal, biochar, biocoke, waste plastics, or industrial by-products KPI promotes the implementation of renewable and recycled carbon materials, reducing reliance on fossil fuel, namely coal and coke.

CO_2 from off-gases reuse KPI capture measures the amount of CO_2 captured by one industry and reused from off-gases by another industry. It reflects the efficiency of utilizing CO_2 from off-gases as a resource. It allows the reduction of net emissions and the repurposing of CO_2 for industrial applications, such as construction materials or extracting valuable hydrocarbons.

Share of carbon content in process gas (CO_2/CO) transformed into products KPI monitors the proportion of CO_2 and CO in process gases converted into value-added products, as mentioned above. It presents the efficiency of carbon capture and utilization technologies, supporting IS.

The TRL KPI assesses the maturity of novel technologies. Regular assessments are needed to determine their current TRL level for the projects where they can be applied.

The defined KPIs address CO_2 emissions reduction, recycling rates, and resource reuse. These indicators evaluate the implementation of IS, ensuring a consistent approach for analysis and reporting. By highlighting the above-mentioned KPIs, the deliverable aligns with the Symbio-Steel project.

Depending on the focus, the Symbio-Steel project will apply one or more of the 11 defined KPIs to assess, monitor, and report on the progress of the funded regional and EU projects in implementing IS.

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