Long- and short-lists of key performance indicators in industry and for industrial symbiosis

Ivan Kantor[1], Hür Bütün[1], Jean-Loup Robineau[1], Samie Maqbool[2], Brecht Zwaenepoel[2], Raphaël Norbert[3], Sebastian Arias[4], Hélène Cervo[5], Franz Wolf[6], and Alessio Santecchia[1]

[1]EPFL
[2]UGent
[3]ArcelorMittal
[4]CEMEX
[5]INEOS
[6]Omya UK Ltd.

March 22, 2019

1 Introduction

A key performance indicator (KPI) is a measurable value that demonstrates how effectively an organisation, process or project is achieving a key objective. For instance, the internal rate of return can be used to measure the effectiveness of a project from an economic perspective, where the objective is profitability. Another example is the CO_2 emissions of an industrial process, which can be calculated to quantify the environmental performance with the objective of mitigating climate change.

Industrial symbiosis (IS) can be defined as the integration of industrial processes from different companies or sectors. The most common example is when industries exchange by-products or waste, including energy. Other examples include the sharing of infrastructure or services by two or more companies. IS can have several benefits for the companies involved, but also for the local community, and even society as a whole. These include aspects of legal, economic, spatial, technical social (LESTS) and environmental benefits. The realisation of those benefits through the implementation of IS needs to be quantified with appropriate KPIs.

The goal of the EPOS project is to implement a decision support toolbox for cross-sectorial IS, providing a wide range of technological and organisational options for making businesses and operations more efficient, more cost-effective, more competitive and more sustainable across various process sectors. The definition of KPIs is a crucial step in the project, as they will allow decision makers to evaluate and compare the solutions proposed by the tool from the different perspectives mentioned.

The first step of the KPIs definition was reported in an EPOS deliverable (D1.4) and consisted of constructing a long list of both sectoral and cross-sectoral KPIs. The sectoral KPIs were provided by the four sector industries of the EPOS project, while the cross-sectoral KPIs were suggested by the universities and Quantis as a result of literature review and experience. The next step was to refine that long list by identifying the most useful KPIs to include in the EPOS toolbox. Since the goal of EPOS is to have a generic framework that can apply to multiple industrial sectors, including those outside of the consortium, care was taken to remove KPIs that were sector specific, and only leave in the ones that all industries could relate to and that

actually evaluated the IS solutions (i.e. cross-sectoral KPIs).
This document presents the long-list of KPIs which were considered and the preliminary short list of KPIs agreed upon by the EPOS consortium, and some discussion of the refinement method applied to achieve it.

2 Industrial KPIs

2.1 Typical KPIs used in the steel industry

As the World's leading Steel and Mining Company, ArcelorMittal's success is built on its core values of sustainability, quality and leadership. In order to cement this leading position over the years, ArcelorMittal is continuously making decisions and acting through a well-defined strategy and taking the right balance sheet to reach the targets identified. As do many companies to support their strategy, ArcelorMittal follows a large amount of metrics (plant operation, security, production, etc.) thus allowing the performance monitoring of its facilities worldwide. These indicators differ depending on the actor following them and that acts accordingly, going from the management committees to the detailed process follow ups. 1 gathers a selection of metrics considered as relevant to the EPOS project framework. They are divided into different categories:

1. Safety, health, quality of working life (for ArcelorMittal collaborators).
2. Use of resources and recycling rates: progress in terms of resource use efficiency.
3. Use of air, land and water: environmental impact assessment.
4. Use of energy: as an energy intensive company due to its process routes and requirements, ArcelorMittal is a responsible energy user that helps create a lower carbon future.
5. Process operation: tracking of influential parameters to make process improvements. For more information about ArcelorMittal's metrics, the ArcelorMittal Corporate website can be consulted (ArcelorMittal).

2.2 Typical KPIs used in the cement industry

As is the case with other industrial sectors, the cement industry utilizes a series of metrics which are industry-standard and are used to objectively measure and then track the performance of a manufacturing facility in terms of energy consumption, throughput and environmental impact among others. For cement plants which manufacture the intermediate product: clinker, the main energy vectors are typically comprised of: coal, fossil fuels, solid and liquid alternative fuels and electricity. The performance for these facilities is usually measured based on specific energy consumptions, specific environmental impacts (mainly air emissions) or specific costs of products. It is important to mention, that the cement industry is very energy intensive and also generates an environmental impact in terms of direct and indirect air emissions. These emissions mainly originate in the cement kiln. The main key performance indicators used in this industry are listed in Table 2.

2.3 Typical KPIs used in the petrochemical industry

By being monitored regularly, they keep track of the value of important parameters or ratios related to the global system performances. The number of KPIs should not be too high and their definition not too complex. As a representative industry in the chemical and petrochemical sector, INEOS defined a list of typical KPIs used in the petrochemical industry and especially on INEOS sites.

Table 3 gives a non-exhaustive list of typical KPIs used to assess INEOS sites' performances. Subsection 3.3.2 describes in detail all the KPIs aforementioned.

Table 1: List of KPIs used in the steel industry

Use	Metric	Unit
Productivity	Crude steel production	$t_{\text{Crude Steel}}$ / year
Safety, health, quality of working life	Number of employees	Number
	Number of contractors	Number
	Lost Time Injury Frequency Rate (LTIFR)	Number per million hours
	Absenteeism rate	%
	Employee turnover rate	%
	Employee training	h / employee / year
	Female collaborators	%
Use of resources and recycling rates	Iron ore	$t_{\text{Iron Ore}}$ / year
	Coal	t_{Coal} / year
	Direct Reduced Iron (DRI)	t_{DRI} / year
	Steel scrap recycled	$t_{\text{Steel Scrap Recycled}}$ / year
	CO_2 avoided from steel recycled	$t_{CO_2 \text{ Steel Recycled}}$ / year
	Residues and by-products re-used	%
	BF slag to Cement industry	$t_{\text{BF Slag}}$ / year
Use of air, land and water	Environmental and energy capital expenditure	€/ year
	Specific dust emissions	t / t_{Steel}
	Specific NO_x emissions	t / t_{Steel}
	Specific SO_x emissions	t / t_{Steel}
	Specific CO_2 emissions	t / t_{Steel}
	Production residues to landfill / waste	%
	Specific net water consumption	Nm^3 / t_{Steel}
Use of energy	Energy intensity	GJ / $t_{\text{Steel Coils}}$
Process operation	Operating time	h / year
	Final product output	$t_{\text{Final Product}}$ / year
	Mean Time Between Failures (MTBF)	h
	Mean Time To Repair (MTTR)	h
	Average daily production	$t_{\text{Final Product}}$ / day
	Specific material inlet stream rate	t / $t_{\text{Final Product}}$
	Specific material outlet stream rate	t / $t_{\text{Final Product}}$
	Specific gas inlet stream rate	Nm^3 / $t_{\text{Final Product}}$ or GJ / $t_{\text{Final Product}}$
	Specific gas outlet stream rate	Nm^3 / $t_{\text{Final Product}}$ or GJ / $t_{\text{Final Product}}$
	Specific utility inlet stream rate	Nm^3 / $t_{\text{Final Product}}$ or GJ / $t_{\text{Final Product}}$
	Specific utility outlet stream rate	Nm^3 / $t_{\text{Final Product}}$ or GJ / $t_{\text{Final Product}}$
	Specific water inlet stream rate	Nm^3 / $t_{\text{Final Product}}$
	Specific water outlet stream rate	Nm^3 / $t_{\text{Final Product}}$
	Specific electricity consumption	MWh / $t_{\text{Final Product}}$

Table 2: List of KPIs used in the cement industry

Use	Metric	Unit
Economic / Efficiency	Specific cost of clinker (SCC)	€/$t_{clinker}$
	Specific cost of cement	€/t_{cement}
	Specific heat consumption (SHC)	kcal/$kg_{clinker}$ or MJ/$t_{clinker}$
	Price of electricity	€/MWh
	Clinker based specific electrical power consumption	kWh/$t_{clinker}$
	Cement based specific electrical power consumption	kWh/t_{cement}
Economic / Environmental	Percentage of AF substitution	%
	Clinker factor	%
Operational	Operational efficiency	%
	Yield	%
Sustainability	Clinker specific net CO_2 emissions	$t_{CO_2}/t_{clinker}$
	"Cementitious product" specific net CO_2 emissions	$t_{CO_2}/t_{cementitious}$
	Kiln emissions	$t_{pollutant}$/ $Nm^3{}_{gas}$

2.4 Typical KPIs used in the mineral industry

In the minerals industry, key performance indicators are used to assess the performance of the industry based on throughput, impact on environment and energy intensity of products. A non-exhaustive list of specific KPIs used by Omya are shown in Table 4.

3 Proposed List of Economic and Sustainability KPIs

3.1 Legal KPIs

3.1.1 Environmental regulatory non-compliances resulting in fines or prosecutions

This legal indicator relates to the performance of an industry on legal issues originating from non-compliance to environmental regulations. This KPI serves two purposes: one, as a performance indicator for the industrial symbiosis projects which may have contributed to this non-compliance; and two, as an indicator to help prioritise improvements/industrial symbiosis projects for an industry.

3.1.2 Environmental license limit exceedances and other non-compliances

This indicator exhibits the environmental performance of an industry or the project that may have led to these non-compliances.

3.1.3 ISO certifications

ISO certifications provide a sustainability level for an industry. For EPOS, the most relevant ISO standards are ISO 9001, ISO 14001, ISO 50001 and OHSAH 18001.

Table 3: List of KPIs used in the chemical industry

Use	Metric	Unit
Resource and energy use	Productivity/Volume produced	t
	Energy Intensity Index (EII)	%
	Specific Energy Consumption (SEC)	GJ or GJp/t
	Energy Efficiency	%
	Condensate return	%
	Steam leaks	-
	Absolute energy consumption	GJ or GJ_p
	Conversion, Yield and Selectivity	%
	Specific catalyst loss	$t_{cat.\ loss}/t_{product}$
	Loss in Flare Gas	$t_{flare\ loss}/t_{flare\ gas}$
	Furnace efficiency	-
	Overall efficiency based on Energy Currency	-
Finance	Earnings Before Interest, Taxes, Depreciation and Amortisation (EBITDA)	k€
	Site Average Margin (SAM)	$/bbl
	Energy prices (natural gas and electricity)	Various
	CO_2 prices	€/t_{CO_2}
	Variable cost	€
	Payback time (PBT)	yr.
Environment	Atmospheric emissions (SO_2, NO_x, NMVOC, benzene, PM, Odours, Ozone, etc.)	Various
	Water effluents (pH, maximum flow rate, temperature, suspended matter, hydrocarbons, N_2, COD/TOD, etc.)	Various
	Wastes (tonnage, recovery rate, dumpster quality indicator, etc.)	Various
	Waste per unit of product	$t_{wastes}/t_{product}$
	Waste based on waste "currency" per unit of product	$t_{wastes}/t_{product}$
Safety & Operability	On Stream Availability (OSA)	%
	Recordable Incident (RI)	-
	LOC10	-
	High Potential Incident (HiPO)	-
	HRO+ days	-
Quality	Approved claims regarding products quality	-

Table 4: List of KPIs used in the industrial minerals industry

Use	Name of key performance indicator	Units
Electricity	Electricity intensity	MWh_{elec} / $t_{product}$
	Power Load Factor (electricity)	%
	Electricity cost	€/ MWh_{elec}
	Specific electricity cost	€/ $t_{product}$
	CO_2 emissions (electricity)	kg_{CO2}eq. / MWh_{elec}
	% of renewable energy in electricity consumption	%
	Renewable own power generation	$MWh_{renewable}$
	Non-renewable own power generation	$MWh_{non\text{-}renewable}$
	Low Tariff Management	%
	Power Factor cos(ϕ)	
	Non-production consumption	%
Gas	Gas intensity	MWh_{gas} / $t_{product}$
	Power Load Factor (gas)	%
	Gas cost	€/ MWh_{gas}
	Specific gas cost	€/ $t_{product}$
	CO2 emissions (gas)	kg_{CO2} / $MWh_{gas\ consumed}$
	Drying Plant process efficiency	%
Production	Quarry Waste	%
	Process Waste	t
	Process Water	m^3
	Chemical Additives	ppm or kg / $t_{product}$

Table 5: List of Legal KPIs

KPI name	Unit	Source
Environmental regulatory non-compliances resulting in fines or prosecutions	number	(Initiative, 2015)
Environmental licence limit exceedances & other non-compliances	number	(Initiative, 2015)
Certifications	List of certifications	
Number of certifications gained by cooperation	number	
Number of certifications maintained by cooperation	number	
Number of certifications lost by cooperation	number	
Level of cooperation	LESTS score	

Table 6: List of common economic KPIs

KPI name	Unit	Source
Generate local business opportunities	yes / no	(Kurup et al., 2005)
Sales	€	(Kurup et al., 2005)
Profit	€	(Kurup et al., 2005)
Wages paid	€	(Kurup et al., 2005)
Tangible environmental costs	€	(Kurup et al., 2005)
Transport costs	€	(Kurup et al., 2005)
Return on Investment	%	(Kimmel et al., 2013)
Internal rate of return	%	(Kimmel et al., 2013)
Payback period	years	(Kimmel et al., 2013)
Discounted payback period	years	(Kimmel et al., 2013)
Net present value	€	(Kimmel et al., 2013)
Return on invested capital	%	(Kimmel et al., 2013)
Capital expenditure	€	(Kimmel et al., 2013)
Operating expenditure	€	(European Commission)
Level of economic cooperation	LESTS score	

3.2 Economic KPIs

3.2.1 Generate local business opportunities

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Some industrial symbioses can generate local business opportunities. For example, this can be in the form of work offered by an industry to a local business which operates & maintains the infrastructure enabling the industrial symbiosis. This indicator is unique in its binary nature, if local business opportunities are not generated or foreseen to be generated, the indicator is 0 or 'no'; however, in the opposite case, this KPI should be 1 or 'yes'.

3.2.2 Sales

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Sales are the revenues resulting from a company's product sales to customers over a period of time (typically a year). This also includes the revenues from the rendering of services to customers. Care should be taken to delimit the perimeter of the entity for which the sales are considered. As an industrial symbiosis study is focused on a specific site, only the sales emanating from that site (and not the whole company) should be considered. Moreover, it should also be clarified prior to the study which products or services are included in the sales. For example, in the case of an incinerator, waste usually has a negative economic value. A business that operates an incinerator will therefore be paid in exchange of receiving waste to eliminate it. Although waste utilisation is not considered as a 'product' per se, it can be viewed as a 'service' and therefore included in the sales revenue calculation. Additionally, co-products or services which are not linked to the core business of the company should also be taken into account (e.g. slag from steel industry, or electricity produced by an incinerator).

3.2.3 Profit

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Profit, also referred to as 'net income', is equal to a company's total revenues minus total expenses over a period of time (typically a year). This value should be reported in the company's income statement. Total revenues include the amount of any assets (usually cash or accounts receivable) received from customers on the sale of goods or services. Total expenses (or expenditures) are all the outflow of assets from the company to any other entity. Similarly to sales, the perimeter for which the profit is considered should be limited to the site considered for the industrial symbiosis study, rather than the whole company. Therefore, earnings collected at the company scale (e.g. dividends) rather than at the site level should not be considered.

3.2.4 Wages paid

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Wages paid, or "wage expense", are the costs incurred for employee's gross wages over a period of time (typically a year), which includes amounts withheld from those wages for payment to government or other entities (e.g. health insurance) on the employee's behalf. Again, the cost perimeter should be clearly identified on a case by case basis, especially when dealing with wages of employees that work in or provide support services common to several sites, or also external contractors whose wages are not directly paid by the company.

3.2.5 Tangible environmental costs

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Tangible costs, as opposed to intangible costs, are costs related to an identifiable source or asset and are therefore easily measurable. In the case of environmental tangible costs, this could correspond to a fine that the company would have to pay if the emissions of a given pollutant are higher than the regulatory threshold. The intangible cost associated could be the loss incurred by the reduced health of employees and thus taking more 'illness' days off. A list of tangible environmental costs needs to be defined, including things such as fines for not respecting regulations, environmental taxes, emissions trading schemes, investments made to reduce environmental impact, campaigns to promote eco-friendly behaviour, etc.

3.2.6 Transport costs

This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Transport costs are associated with the transportation of raw materials or goods provided to/by the industrial site from/ to another entity. The transport costs considered need to be clearly defined. First of all, it should be clarified if the investment cost of the transportation medium (e.g. railcar) should impact the transport cost, or only the costs related to the transport itself (e.g. fuel and operator wages). Secondly, the origin/destination of the product should be wisely chosen. For example, an input raw material could have first been transported from a mine (belonging to a mining company) to a storage warehouse (belonging to a distributor), and then further transported to the industrial site considered. In that case, it must be well-defined whether the transport cost should be from the distributor warehouse or from the mine.

3.2.7 Return on investment

Return on investment (ROI) is a performance measure to evaluate the efficiency of an investment. It measures the amount of financial return on an investment relative to the investment's cost. The formula is:

$$ROI = \frac{Gain\,from\,investment - Cost\,of\,investment}{Cost\,of\,investment} \tag{1}$$

The gain from investment could also be associated with the savings incurred from buying infrastructure enabling industrial symbiosis actions. For example, the investment could be a pipe which allows sending excess steam from one company to another, which would have otherwise been lost. The gain (for the overall system consisting of both companies) would be the total fuel savings compensated by the exchanged steam. More information can be found in (Kimmel et al., 2013).

3.2.8 Net present value

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The cash flows are discounted back to their present value using a discount rate in order to take into account the time value of money. NPV is used to analyse the profitability of a projected investment or project in the current time. The following formula is used for calculating the NPV:

$$NPV = \sum_{t=1}^{N_t} \frac{C_t}{(1+r)^t} - C_0 \tag{2}$$

Where:
- C_t is the net cash inflow (revenue-expenses) during period t
- C_0 is the total initial investment cost
- r is the discount rate
- t is the time period
- N_t is the number of time periods

A positive NPV indicates the projected earnings generated by a project or investment (in present currency) exceeds the anticipated costs (also in present currency). Generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss. More information can be found in (Kimmel et al., 2013).

3.2.9 Internal rate of return

Internal rate of return (IRR) is the discount rate that makes the NPV from a particular project equal to zero over a given period of time. The higher a project's internal rate of return, the more desirable it is to undertake the project. IRR is uniform for investments of varying types and, as such, it can be used to rank multiple prospective projects on a relatively even basis. Assuming the investment costs of various projects are equal, the project with the highest IRR would probably be considered the best from an economic point of view. More information can be found in (Kimmel et al., 2013).

3.2.10 Payback period

The payback period (PBP) is the length of time required to recover the cost of an investment. It is calculated by dividing the initial investment by the yearly cash inflow. The payback period is an important determinant of whether to undertake the project or investment, as longer payback periods are less desirable. The payback period ignores the time value of money, unlike other methods of capital budgeting such as net present value or internal rate of return. More information can be found in (Kimmel et al., 2013).

3.2.11 Discounted payback period

The discounted payback period gives the number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and recognising the time value of money. In other words, it is the number of time periods from which the net present value becomes positive for a given discount rate. This indicator is adapted from PBP to account for the time value of money which is often considered to be a weakness in non-discounted PBP calculations, especially over longer time horizons. More information can be found in (Kimmel et al., 2013).

3.2.12 Return on invested capital

Return On Invested Capital (ROIC) is a measure used to assess a company's efficiency at allocating the capital under its control to profitable investments. ROIC gives a sense of how well a company is using its money to generate returns. One way to calculate it is:

$$ROI = \frac{Operating\,income\,attributed\,to\,capital\,investment - Taxes}{Invested\,capital} \quad (3)$$

More information can be found in (Kimmel et al., 2013).

3.2.13 Capital expenditure

Capital expenditure (capex) are the funds required to acquire or upgrade physical assets such as property, industrial buildings or equipment. This is an important consideration for projects as companies will have limited funds that they can mobilise, ruling out certain projects regardless of their profitability. If there is a strong interest in a project that exceeds the company's funding capabilities, funding from external sources will have to be sought. More information can be found in (Kimmel et al., 2013).

3.3 Spatial KPIs

Table 7: List of Spatial KPIs

KPI name	Unit	Source
Efficient use of land	number of activities / km^2	
Distance between the partner industries	km	
Availability of major connections (routes / channels) between partner industries	List of modalities	
Economic intensity	€/km^2	
Level of economic cooperation	LESTS ranking	

3.3.1 Efficient use of land

Multiple land use is an objective of efficient land use. This indicator will be affected significantly by the number of activities being performed in the area.

3.3.2 Distance between dispatching and receiving nodes

This indicator is specifically defined for industrial symbiosis projects. Distance between two or more industries is a crucial parameter which defines the economic suitability of an industrial symbiosis. The distance between the industries shows the distance covered via a transport route connecting the industries.

3.3.3 Availability of major connection routes / channels between partner industries

Effective connection routes between partner industries within an industrial symbiosis is a crucial indicator, especially if the industries are not located in immediate proximity to one another.

3.3.4 Economic intensity

This metric represents the profit generated per land area used for the industrial activities. The higher the value, the less impact economic activities will have on land usage, which is in line with the general idea of going towards a more densified society, leaving more space for natural habitats.

3.4 Technical KPIs

A list of technical KPIs defined in literature were identified and are listed in Table 8. Each of these is then described in more detail in the following subsections.

Table 8: List of Technical KPIs

KPI Name	Short description	Unit	Source
Domestic Material Input DMI	Domestic extraction (DE) + imports	t	(Sendra et al., 2007)
Total Material Requirement TMR	Direct material input + indirect flows + unused DE	t	(Sendra et al., 2007)
DMIw (t/worker)	DMI/number of workers	t/worker	(Sendra et al., 2007)
TWGw (t/worker)	TWG/number of workers	t/worker	(Sendra et al., 2007)
Worker Productivity WP	Total production/number of workers	t/worker	(Sendra et al., 2007)
Total Water Input TWI	Total water consumption	t	(Sendra et al., 2007)
Total WasteWater Generated TWWG	Total amount of waste water produced	t	(Sendra et al., 2007)
Total Water Input /worker	TWI/number of workers	t/worker	(Sendra et al., 2007)
Total Energy Input	Total energy consumption	GJ	(Sendra et al., 2007)
Total Energy Input per worker	TEI/number of workers	GJ/worker	(Sendra et al., 2007)
Energy Intensity E-In	TEI/total production	GJ/t	(Sendra et al., 2007)
Energy efficiency	energy in products/total energy in	%	
Exergy efficiency	product exergy/ input exergy	%	
Material efficiency	mass of (products out /raw materials in)	%	
Level of technical cooperation	0 – no technical feasible cooperation to 5, principles of circular economy met	LESTS score	

3.4.1 Domestic Material Input (DMI)

The DMI is an indicator derived from material flow analysis (MFA) and is the measure of material flows to be used in the system. The materials used in the system can be domestic (i.e. from own sources) and/or imported. Hence DMI is the sum of domestic extraction and imports. It is used to indicate the material requirement of a system as well as to reflect co-product exchange between sub-systems (Sendra et al., 2007). The DMI of a system can be improved by increasing exchange between the subsystems while the DMI of the subsystems will remain the same. As DMI is directly linked to the size of the system, for comparing two or more systems, normalization with another parameter which is linked to the system size is required. This leads to another indicator, the DMIw, which is DMI divided by the number of workers.

3.4.2 Worker Productivity (WP)

The WP is a measure to assess the efficiency of a group of workers. It is calculated by dividing the amount of output (product) to the number of workers producing that output. The output can be considered as product (material) itself or the revenue it brings. In the EPOS project, when using this KPI, the focus will be on the material itself.

3.4.3 Total Water Input (TWI)

Total water consumption of a system can be represented with TWI. Water usage can be from domestic sources or imported from outside sources such as city water networks, lakes and rivers. It is important to note that natural water sources such as lakes and rivers do not fall in the category of domestic sources as they generally cross the system boundaries and are shared with other systems (Sendra et al., 2007). Domestic sources, therefore, include only water coming from rain or use of water from a surface source on-site or reclaimed at the site. The TWI is a sum from all sources. Similar to other KPIs identified from MFA, this parameter can be normalized by dividing it by the number of workers, which results in total water input per worker (TWIw).

3.4.4 Total Wastewater Generated (TWWG)

As explained in Section 4.6, the total waste generation indicator (TWG) does not include wastewater. Hence a separate measure is used for wastewater generation. The TWWG is the total waste water that is generated by the processes in the system. Commonly TWI and TWWG of companies are similar: the more the TWI the more the TWWG (Sendra et al., 2007). For systems with dissipative usage of water, such as evaporation processes, TWI is higher than TWWG.

3.4.5 Total Energy Input (TEI)

Total net energy required by the system is called as total energy input. As the energy flows are measured at the entrance of the system, their efficiencies are accounted within the TEI indicator (Sendra et al., 2007). Therefore, the definition of the system and its boundaries is important when determining this KPI. The normalisation of this parameter is completed, as with several indicators, by dividing TEI by the number of workers to obtain the total energy input per worker, TEIw.

3.4.6 Energy Intensity (E-In)

As the TEI is directly linked to the production rate of a system, it is difficult to use as a comparative indicator between systems with differing products. The E-In, therefore, is used to indicate the specific energy required for a unit of product. It is calculated by dividing the TEI by production to obtain the result in units of GJ/tonne.

3.4.7 Energy Efficiency

Energy efficiency is, in general, referred to as the ratio of output energy to input energy. It can be defined for a process, equipment, cycle etc. Therefore, when calculating energy efficiency, the choice of system boundaries is important as the inputs and outputs are determined based on them. Energy efficiency can also be referred to as 'thermal efficiency' or 'first law efficiency' and can also be estimated using losses when the output energy is not measured or more difficult to obtain accurately.

$$\eta_E = \frac{E_{out}}{E_{in}} = 1 - \frac{\sum E_{loss}}{E_{in}} \tag{4}$$

Where:
- η_E is the energy efficiency
- E_{out} is the energy output
- E_{in} is the energy input
- E_{loss} is the energy lost

3.4.8 Exergy efficiency

Exergy is defined as the maximum work that can be achieved by a material by reversible exchanges with the environment (Borgnakke et al., 2009). Exergy efficiency is the ratio of output exergy from a system to input exergy to the system. It can be referred to as 'second law efficiency' as well. This is expressed similarly to energy efficiency, where B represents exergy:

$$\eta_B = \frac{B_{out}}{B_{in}} = 1 - \frac{\sum B_{loss}}{B_{in}} \tag{5}$$

3.4.9 Material Efficiency

Material efficiency has multiple definitions. It can be referred to as the ratio of material flows that are used in the processes to the total material flow to the system. Alternatively, it may be referred to as the ratio of product flows to raw material flows. The choice for which definition to use in the EPOS project will be considered during the selection of cross-sectorial KPIs.

3.5 Social KPIs

3.5.1 Health and Safety KPIs

Fatalities (employees only) This is the number of employees who have experienced a fatal event.

Lost Time Injury (employees only) A lost time injury is the time (days) that could not be worked by the worker due to an occupational accident or disease resulting from a non-fatal injury arising out of or in the course of work.

Near misses A near miss is an unplanned event that did not result in injury, illness, or damage – but had the potential to do so. It is typically tracked as part of plant safety records.It is

First aid injuries Injuries which could be treated onsite, resulting in no further medical treatment.

Medical treatment injuries Injuries requiring intervention of medical personnel, directly after the incident or some time after the incident occurred. No further work absence required after treatment.

Restricted work injuries Injuries resulting in absence of work longer than required for the treatment.

Occupational illness Illness resulting from the nature of the work carried out during prolonged time or exposure to hazards.

3.5.2 Skill level

This is accounted for as the average number of hours of training per employee, i.e. the total number of training hours divided by the total number of employees.

3.5.3 Social Responsibility in supply chain

A sketch of all the supply chain actors An overview of all actors directly involved within the supply chain and their interactions.

Table 9: Social KPIs

KPI name	**Unit**	**Source**
Fatalities (employees only)	#	(Initiative, 2015)
Lost Time Injury (employees only)	#	(Initiative, 2015)
Near misses	#	
First aid injuries	#	
Medical treatment injuries	#	
Restricted work injuries	#	
Occupational illness	#	
A sketch of all the supply chain actors	y/n	
Ratio of supply chain actors showing their commitment to CSR (Corporate Social Responsibility) criteria	%	
Taxation revenue	€	(Kurup et al., 2005)
Membership in an initiative that promotes social responsibility along the supply chain (number of enterprises)	#	(Sala et al., 2015)
Skill level	number	(Initiative, 2015)
Leadership positions held by women	%	(Initiative, 2015)
Ratio of salary of female employee wages to male employee wages	%	(Sala et al., 2015)
Ratio of female employees	%	
Ratio of employees with a foreign origin	%	
Job security - Percentage of workers with a long-term contract	%	(Sala et al., 2015)
Evidence of violations of laws and employment regulation	#	(Sala et al., 2015)
Mechanism for registering grievances of community	y/n	
Aesthetic and visual acceptability	number of complaints	
Noise	decibels + number of complaints	
Dust	number of complaints	
Odour	number of complaints	
Workforce employed locally	%	
Social level of cooperation	LESTS score	

Ratio of supply chain actors showing their commitment to CSR (Corporate Social Responsibility) criteria Number of supply chain actors practicing CSR. CSR policy is usually regarded as a self-regulatory mechanism whereby a business monitors, and ensures its active compliance with the legal framework, common ethical standards and internationally agreed norms. Arguably, a firm's implementation of CSR goes beyond mere adhering to the existing legal framework and involves "actions that appear to further some social good, beyond the interests of the firm and that which is required by law".

Taxation revenue This indicator is listed in (Kurup et al., 2005) as a publicised indicator for economic impacts of industrial symbiosis projects. Taxation revenue represents the taxes paid by the company. One should only consider the taxes emanating from the site under study.

Membership in an initiative that promotes social responsibility along the supply chain (number of enterprises) Number of participations in social responsibility programmes

3.5.4 Non-discrimination

Leadership positions held by women Ratio of women in leadership positions to total number of leadership positions

Ratio of salary of women wages to men Salary balance between male and female employees

Ratio of female employees Female employees compared to total employees.

Ratio of employees with a foreign origin Employees of foreign origin to total employees.

Job security - Percentage of workers with a limited duration contract Ratio of employees with a contract of limited duration.

Evidence of violations of laws and employment regulation Number of complaints/convictions regarding employees contracts.

Workforce employed locally Number of employees from the local region / total population within the hiring age range (18 – 65).

3.5.5 Social responsibility towards the community

Mechanism for registering grievances of community Indicating if a system for registering and treatment of community complaints is in place.

Aesthetic and visual acceptability Number of complaints about visual pollution.

Noise Average noise measured outside the plant / number of reasonable complaints.

Dust Number of complaints about dust emissions.

Odour Number of complaints about odour.

3.6 Environmental KPIs

Table 10: Environmental KPIs

KPI name	Unit	Source
Total production volume	M t	(Initiative, 2015)
Raw materials used	M t	(Initiative, 2015)
Materials for packaging purposes	M t	(Initiative, 2015)
Total on-site energy consumption from renewable sources	%	(Initiative, 2015)
CO_2e emissions from power generation	k t	(Initiative, 2015)
NO_x emissions	k t	(Initiative, 2015)
SO_x emissions	k t	(Initiative, 2015)
Total particulate emissions	k t	(Initiative, 2015)
Water withdrawal from marine water sources	M m^3	(Initiative, 2015)
Water withdrawal from freshwater sources	M m^3	(Initiative, 2015)
Water withdrawal from municipal water sources	M m^3	(Initiative, 2015)
Water discharged- cooling water to marine water sources	M m^3	(Initiative, 2015)
Water discharged- treated wastewater to marine water sources	M m^3	(Initiative, 2015)
Water discharged- treated wastewater to freshwater sources	M m^3	(Initiative, 2015)
Water discharged- waste water to sewerage	M m^3	(Initiative, 2015)
Water discharged- waste water to other destinations	M m^3	(Initiative, 2015)
hazardous waste produced	t (solid) or m^3 (liquids)	(Initiative, 2015)
hazardous waste recycled	t (solid) or m^3 (liquids)	(Initiative, 2015)
Non-hazardous waste produced	t (solid) or m^3 (liquids)	(Initiative, 2015)
Non-hazardous waste recycled	t (solid) or m^3 (liquids)	(Initiative, 2015)
Direct GHG emissions	M t CO_2eq or kg CO_2eq/ $t_{product}$	(Initiative, 2015)
Total waste sent to landfill	k t	(Initiative, 2015)
Carcinogens	kg C_2H_3Cl eq	(Jolliet et al., 2003)
Non-carcinogens	kg C_2H_3Cl eq	(Jolliet et al., 2003)
Respiratory inorganics	kg $PM_{2.5}$ eq	(Jolliet et al., 2003; IMPACT World+, 2012)
Ionising radiation	Bq	(Jolliet et al., 2003; IMPACT World+, 2012)
Ozone layer depletion	kg CFC-11 eq	(Jolliet et al., 2003; IMPACT World+, 2012)
Respiratory organics	kg C_2H_4 eq	(Jolliet et al., 2003)
Aquatic ecotoxicity	kg TEG water	(Jolliet et al., 2003)
Terrestrial ecotoxicity	kg TEG soil	(Jolliet et al., 2003)
Terrestrial acidification/nutrification	kg SO_2 eq	(Jolliet et al., 2003; IMPACT World+, 2012)

Land occupation	m^2org arable	(Jolliet et al., 2003)
Aquatic acidification	kg SO_2 eq	(Jolliet et al., 2003)
Aquatic eutrophication	kg $PO_4{}^{3-}$ (P-limiting)	(Jolliet et al., 2003)
Global warming	kg CO_2 eq	(Jolliet et al., 2003; IMPACT World+, 2012)
Non-renewable energy	MJ primary	(Jolliet et al., 2003)
Mineral extraction	MJ surplus	(Jolliet et al., 2003)
Land occupation, biodiversity	ha.yr arable	(IMPACT World+, 2012)
Fossil energy use	MJ deprived	(IMPACT World+, 2012)
Mineral resources use	kg deprived	(IMPACT World+, 2012)
Water use	m^3 deprived	(IMPACT World+, 2012)
Aquatic eutrophication	kg $PO_4{}^{3-}$ (P-limiting)	(IMPACT World+, 2012)
marine eutrophication	kg N eq	(IMPACT World+, 2012)
Aquatic ecotoxicity, short-term	CTUe	(IMPACT World+, 2012)
Aquatic ecotoxicity, long-term	CTUe	(IMPACT World+, 2012)
Respiratory organics	kg NMVOC eq	(IMPACT World+, 2012)
Carcinogens, short-term	CTUh	(IMPACT World+, 2012)
Carcinogens, long-term	CTUh	(IMPACT World+, 2012)
Carcinogens, indoor	CTUh	(IMPACT World+, 2012)
Carcinogens, pesticides residues	CTUh	(IMPACT World+, 2012)
Non-carcinogens, short-term	CTUh	(IMPACT World+, 2012)
Non-carcinogens, long-term	CTUh	(IMPACT World+, 2012)
Non-carcinogens, indoor	CTUh	(IMPACT World+, 2012)
Non-carcinogens, pesticides residues	CTUh	(IMPACT World+, 2012)
Human health	DALY	(Jolliet et al., 2003; IMPACT World+, 2012)
Ecosystem quality	PDF m^2 yr	(Jolliet et al., 2003; IMPACT World+, 2012)
Climate change	kg CO_2 eq	(Jolliet et al., 2003)
Resources	MJ primary	(Jolliet et al., 2003)
Total material requirement per worker	t/worker	(Sendra et al., 2007)
Total Waste Generated	t	(Sendra et al., 2007)
Eco-Efficiency	none	(Sendra et al., 2007)
Eco-Intensity	none	(Sendra et al., 2007)
Material Inefficiency	none	(Sendra et al., 2007)

3.6.1 Life-cycle assessment-based methodologies

Life-cycle assessment (LCA) is one of the most systematic methods currently available and standardized by the ISO to address environmental impacts from a product or process. The details of the methodology will not be included here; rather, the categories used in two popular impact assessment methodologies are presented as being potential KPIs for use in the EPOS project. One important distinction must be made between midpoint and endpoint categories. Midpoint categories are typically the first level of aggregation following the life-cycle inventory data which are the real data from the production process. These categories are meaningful on their own to some audiences but individually cannot address the entire impact on meaningful sectors of people or plant. Endpoint categories are an aggregated set of midpoints with the intention of providing more meaningful and generalizable results for the user. Both levels of impact category are relevant and thus both are presented here. The categories used are taken from the IMPACT 2002+ method developed at EPFL in Switzerland and IMPACT World+ which was developed as an international collaboration to address regional specificities for different impact categories. Endpoint impact categories will be presented first, followed by the contributing midpoint categories.

Human Health Human Health is an endpoint impact category used in both IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+ (IMPACT World+, 2012) though the dependencies differ between the two methods. In IMPACT 2002+, this category accounts for Human Toxicity, Respiratory Effects, Ionizing Radiation and portions of Ozone Layer Depletion and Photochemical Oxidation. In IMPACT World+, the contributing midpoint indicators are Human Toxicity, Photochemical Oxidation, Ozone Layer Depletion,Depletion, Global Warming and Water Use. In both characterization methodologies, however, the units used for measurement of the endpoint category are Disability Adjusted Life Years (DALY) which refer to the years of life which are degraded or lost as a result of the activity studied, averaged over a population. Thus, for the population affected, the DALY will be averaged over that population.

Ecosystem Quality The Ecosystem Quality endpoint indicator is common between the IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+ (IMPACT World+, 2012) methods discussed here but as with the Human Health category, the midpoint indicators that contribute are slightly different. In the IMPACT 2002+ method, this endpoint category includes Aquatic Ecotoxicity, Terrestrial Ecotoxicity, Aquatic acidification and eutrophication, Land occupation, Terrestrial acidification and elements of Ozone Layer Depletion and Photochemical oxidation. Resource Use, Land Use, Water Use, Eutrophication, Acidification, Ecotoxicity, Global Warming and Ozone Layer depletion are all included in this endpoint impact category. The units of measurement considered for Ecosystem Quality are PDFm2yr which is the potentially disappeared fraction of species (PDF) in an area of 1m2 in one year as defined by Jolliet (Jolliet et al., 2003).

Climate Change Climate Change is used as an endpoint impact category in IMPACT 2002+(Jolliet et al., 2003) and is measured in kg CO_2 eq, as is the contributing midpoint category of Global Warming. Climate change is often referred to as being the most pressing concern for sustainability and is often referred to in literature as a reason to reduce fossil fuel consumption. Climate Change is not used as an Endpoint category by IMPACT World+ *per se* but instead spans all impact categories in the methodology or it can be treated separately if its contributions to the other categories are not double-counted (i.e. If Climate Change is considered as a separate endpoint category, its impacts cannot be included in the Ecosystem Quality endpoint impact category)

Resources (and Ecosystem Services) Resources is an endpoint category in IMPACT 2002+ (Jolliet et al., 2003) which encompasses the midpoint categories of Mineral Extraction and Non-renewable Energy Consumption. It represents a measure of damage caused by depleting the resources of the planet, specifically the energy/fuel resources. The units of measure are in MJ primary energy eq as are the two contributing midpoint categories. The IMPACT World+ system (IMPACT World+, 2012) defines this endpoint category as Resources and Ecosystem Services with contributions from the midpoint categories of Water Use, Land Use and Resource Use.

Carcinogens The Carcinogen indicator relates to the amount of cancer-inducing chemicals which are emitted by an activity. The measurement is made in equivalencies of vinyl chloride (C2H3Cl), also commonly referred to as VC or VCM for vinyl chloride monomer. Carcinogens are a midpoint indicator in the IMPACT 2002+ (Jolliet et al., 2003) method and contribute to the endpoint indicator of Human Toxicity. This category should be considered in any cases where highly carcinogenic products, co-products or wastes are used or produced. In the IMPACT World+ methodology, carcinogens are split into short-term, long-term, indoor and pesticide residues and are measured in comparative toxic units for humans (CTUh), following the definition of the USETox (Henderson et al., 2011; Rosenbaum et al., 2008, 2011) system for chemicals toxic to humans.

Non-Carcinogens This midpoint category from IMPACT 2002+ (Jolliet et al., 2003) refers to non-carcinogenic chemical compounds which have other effects on human health. The equivalency unit used is the same as for carcinogens, chloroethene (C2H3Cl), but refers to chemical compounds which are not carcinogenic for humans but lead to decreased life expectancy or quality of life on the same basis. The combination of Carcinogens and non-carcinogens make up the midpoint indicator of Human Toxicity which then contributes to the endpoint indicator of Human Health Impacts. Similarly to carcinogens, the IMPACT World+ (IMPACT World+, 2012) represents non-carcinogens in a variety of settingstemporal scales, namely: short-term, long-term, indoor and pesticide residues. The unit of measure is also the same as for carcinogens, CTUh.

Respiratory Inorganics This midpoint indicator for Eco-indicator 99 (Goedkoop and Spriensma, 2001), adopted into IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+, reflects upon damage caused by small particulate matter. The reference unit for this category is kg $PM_{2.5}$ eq which is to say, particles of diameter less than 2.5 microns. This category covers all small particulate matter and the respiratory issues induced in humans from such small particulates. As such, this midpoint category is carried further into the endpoint category of Human Health Impacts.

Ionizing Radiation Ionizing radiation is the type of radiation specifically problematic for health impacts in humans. Ionizing radiation is a midpoint category in IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+ (IMPACT World+, 2012) to account for the radiation exposure for a product or process, measured in Bq ^{14}C eq emitted to air as the base unit for this category. This midpoint category is included in the Human Health Impact endpoint category.

Ozone Layer Depletion Depletion of the Ozone layer is adopted from the Eco-indicator 99 methodology (Goedkoop and Spriensma, 2001) and treated as a midpoint category within the IMPACT 2002+ (Jolliet et al., 2003) and adopted verbatim within the IMPACT World+ (IMPACT World+, 2012) framework. The units used for this category are kg CFC-11 eq, relating the impact of a product or process to the same impact on ozone layer depletion by CFC-11 which is one of the problematic refrigerants identified as being the cause of massive ozone depletion. This midpoint category is factored into the endpoint categories of Human Health Impacts and Ecosystem Quality.

Respiratory Organics (Photochemical Oxidation) Both IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+ (IMPACT World+, 2012) have have a midpoint indicator for Respiratory Organics, sometimes referred to as Photochemical Oxidation for the reason that the main danger for humans is the photochemical synthesis of smog. The IMPACT 2002+ midpoint category has units of kg ethene (C_2H_4) eq whereas the IMPACT World+ method refers to non-methane volatile organic compounds which are the reagents for the formation of photochemical smog. In both methods, this midpoint category has an impact on the endpoint categories of Human Health and Ecosystem Quality.

Aquatic Ecotoxicity The midpoint indicator for aquatic ecotoxicity is used in IMPACT 2002+ (Jolliet et al., 2003) as a midpoint category based on the equivalent level of triethylene glycol (TEG) which is emitted to air, water and land but refer to the impacts on fresh surface water. As this midpoint indicator is directly linked to the impact of activity on the natural system, it is included in the endpoint category of Ecosystem Quality according to IMPACT 2002+. The IMPACT World+ (IMPACT World+, 2012) Method dichotomizes this category into Aquatic ecotoxicity in the short- and long-term to create the distinction between acute and chronic effects in aquatic ecosystems. The unit of measure also differs for IMPACT World+, being recorded in comparative toxic units (CTU) which is then specifically adapted to the aquatic ecotoxicity impact category and used as CTUe following the definitions of USETox (Henderson et al., 2011; Rosenbaum et al., 2008, 2011).

Terrestrial Ecotoxicity This is similar to Aquatic ecotoxicity and is based on the same metrics but refers specifically to emissions to soils. Indeed, the reference unit of kg TEG emitted to soil is also used for this midpoint indicator. As with aquatic ecotoxicity, terrestrial ecotoxicity contributes to the endpoint impact category of Ecosystem Quality.

Terrestrial Acidification/Nutrification Contrary to the case in aquatic systems, terrestrial acidification and eutrophication are grouped into one midpoint impact category in IMPACT 2002+ (Jolliet et al., 2003) and IMPACT World+ (IMPACT World+, 2012). The basis units are kg SO_2 eq emitted to air which are then assumed to cause terrestrial acidification. The nutrification portion of this category must also be converted into the same equivalent units though the methodology for this conversion is unclear in the literature.

Land Occupation The land occupation impact category builds on work from Eco-indicator 99 (Goedkoop and Spriensma, 2001) and uses m^2 organic arable land eq required or affected by the product or process in question. This midpoint indicator speaks to the use of land that could otherwise exist in its natural statestatestatestate and thus contributes to the endpoint indicator of Ecosystem Quality.

Aquatic Acidification This midpoint impactimpact category relates to the acidification (pH depression) of water systems. The measurement units for this category are kg SO_2 eq emitted to air. The units of SO_2 eq emitted to air are specifically used for this purpose as atmospheric SO_2 will eventually converted to dilute Sulfuric acid by reaction with atmospheric water vapour. As such, the acidification potential of any of acidifying substance must be converted to the acidification potential of SO_2. The aquatic acidification midpoint impact category is factored into the endpoint category of Ecosystem Quality.

Aquatic Eutrophication Eutrophication is increased nutrient availability or concentration in water which causes excessive growth of plant species. Such activities disrupt natural ecosystems and thus this IMPACT 2002+ (Jolliet et al., 2003) midpoint indicator is included in the calculation of the endpoint category of Ecosystem quality. The midpoint indicator units are kg PO_4^{3-} eq into water by default. In regions where nitrogen is the limiting factor in plant growth, the midpoint basis unit is a nitrogenic species but for simplicity in this document, the basis units are defined as kg PO_4^{3-} eq into water. IMPACT World+ (IMPACT World+, 2012) uses Aquatic Eutrophication as a midpoint impact category in the same way but also has an additional midpoint impact category of Marine Eutrophication which relates to other bodies of water such as seas and oceans (as opposed to fresh surface water).

Global Warming The Global Warming midpoint impact category indicates the contribution of the subject of study to the increase in global warming associated with the greenhouse effect. The units of measurement are kg CO_2 equivalent and is one of the major foci on many policies and studies with regard to sustainability and future policy on industrial production. Using the IMPACT 2002+ (Jolliet et al., 2003) methodology, this midpoint indicator contributes to the endpoint impact category of Climate Change and is indeed its only contributor. The IMPACT World+ (IMPACT World+, 2012) method treats the Global Warming midpoint indicator slightly differently, as a contribution both to Ecosystem Quality and Human Health.

Non-renewable Energy The IMPACT 2002+ (Jolliet et al., 2003) impact category of Non-renewable Energy specifically refers to the specific primary energy demand of the product or process. The midpoint units are MJ primary energy extracted and use the higher heating value for combustible fuels. This midpoint category further contributes to the Resource endpoint impact category.

Mineral Extraction The mineral extraction midpoint category in IMPACT 2002+ (Jolliet et al., 2003) contributes together with Non-renewable Energy to provide the endpoint Resource impact category. The calculations for this indicator are expressed in units of specific MJ of surplus energy as from Eco-indicator 99 (Goedkoop and Spriensma, 2001). This calculation represents an extrapolation of the energy demand of the mineral product over an unknown lifetime of the mining activity based on cumulative demand in a given period.

Land Occupation, Biodiversity This indicator is a midpoint impact category of Impact World+ (IMPACT World+, 2012) and represents similar information to the Land Occupation category in Impact 2002+ but is expressed in units of ha yr arable land, expressing the land use and biodiversity impact as a loss of arable land and habitat for animals.

Fossil Energy Use This midpoint impact category of IMPACT World+ (IMPACT World+, 2012) bears a resemblance to the Non-renewable Energy category used in IMPACT 2002+ but is expressed specifically for the use of fossil energy. The units of measure are MJ primary energy deprived, meaning that this energy is no longer available for other uses. This midpoint impact contributes to the midpoint category of resource use and thus the endpoint categories of Ecosystem Quality and Resources and ecosystem Services.

Mineral Resources Use Mineral Resources Use, like Fossil Energy Use, bears a resemblance to the IMPACT 2002+ midpoint impact category of Mineral extraction but is instead measured in kg deprived. This refers to the deprivation of future potential users of this resource. This midpoint impact contributes to the midpoint category of resource use and thus the endpoint categories of Ecosystem Quality and Resources and ecosystem Services.

Water Use This midpoint impact category of IMPACT World+ (IMPACT World+, 2012) indicates the volume of water that is used which is therefore no longer available for use by other processes. As such, the reference unit for the category is m^3 deprived, meaning that that water is unusable by other processes. This midpoint impact category further contributes to the endpoint of Resources and Ecosystem Services.

3.6.2 Global Reporting Initiative Indicators

The global reporting initiative (GRI) is an independent organization with the mission to standardize industrial reporting on sustainability. Selected indicators from are suggested here for use in EPOS.

Raw Materials Used This indicator is based on the G4 Sustainability Reporting Guidelines (G4SRG) (Initiative, 2015) and is simply the total mass of material used to produce (and package) the main products and service of an industry. The guideline also suggests reporting in the two sub-categories of renewable and non-renewable materials used. The units suggested for this indicator are Mtonnes.

Materials for Packaging Purposes Similar to the indicator of Raw Materials Used, this indicator is simply a report of the mass of material which is used for packaging the main products or services of a company. As with the parent category, the units suggested for this indicator are Mtonnes.

On-site Energy Consumption from Renewable Sources This indicator from the G4SRG (Initiative, 2015) is an indication of percentage of site energy demand that is met by renewable sources. It is calculated by dividing the amount of renewable energy utilized by the total site energy demand. If the company exports energy products, this is accounted for by subtracting the exports from the imports in the denominator of the calculation.

Direct CO_2eq emissions This indicator (based on G4-EN15 (Initiative, 2015)) reflects the equivalent CO_2 emissions from site operations. This refers to the direct emissions from processes on the site and does not include the indirect effects from importing materials or energy from outside of the site boundary. As stated in the guide: "GHG emissions in metric tons of CO_2 equivalent, independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances."(Initiative, 2015)

NO_x Emissions This indicator is a subset of G4-EN21 (Initiative, 2015) of the G4SRG specifically focusing on NO_x emissions as being one of the most relevant emissions to air that can be measured on sites. NO_x are of particular importance as they are limiting reagent in photochemical smog formation in some jurisdictions but can also contribute to acidification and nutrification generally. This indicator is intended to showcase the total amount of NOx emissions from an industry.

SO_x Emissions Similar to the emissions of NO_x, SO_x emissions are a subset of the G4-EN21 (Initiative, 2015) reporting and are specifically referred to as a significant emission. As mentioned for the indicators based on LCA, SO_x contribute to terrestrial and aquatic acidification and are thus the focus of a specific indicator.

Total Particulate Emissions The total emissions of particulate matter from a process is another airborne emission indicator based on G4-EN21 (Initiative, 2015). This indicator refers to the total direct emissions of particulate matter (diameter less than 100 microns) to the air. Such emissions have health impact for nearby populations and workers and should be kept as low as possible. Of particular concern are particulates of diameter less than 2.5 microns which have greater health consequences than larger particles. Thus, the diameter used for this indicator could be modified according to the most relevant particle size.

Water Withdrawal Three indicators are suggested for addressing water withdrawal based on G4-EN8 (Initiative, 2015). These indicators cover withdrawal from marine sources, freshwater sources and municipal sources. The indicator for each source should be reported as a separate quantity according to G4-EN8 and measured in Mm^3. For adaption to industrial symbiosis situations, an additional category of water from other industries could also be measured. Reporting could also be done using system of percentages though the absolute values can be useful for representing the scale of industries as well.

Water Discharge Water discharge is suggested by G4-EN22 (Initiative, 2015) to be recorded by the final disposition including treatment. As such, the suggestion here is to include five measurements, or a relevant subset thereof, of: cooling water to marine destination, treated wastewater to marine water sources, treated wastewater to freshwater sources, wastewater to sewerage and wastewater to other destinations. As with water withdrawal, the recommended unit of measure for water discharge is Mm^3. Additional destinations could be included, such as wastewater sent to a non-treatment industry which may be especially relevant for IS scenarios.

Hazardous Waste Following G4-EN23 (Initiative, 2015), hazardous waste should be classified as such by local legislation for each site and measures in tonnes for solids and m^3 for liquids. The fate of the waste should be accounted for by noting the total hazardous waste production as well as the amount that is recycled. The definition of recycling could be extended to include the reuse of such hazardous waste by neighbouring industries.

Non-hazardous Waste The suggestion for non-hazardous waste is similar as that for Hazardous Waste but of course is separated by local legislation which specifies materials as being hazardous or not. The units should also be similar, measured in tonnes for solids and m^3 for liquids. As with hazardous waste, the category could be split into the total production and also allow for a specification of the amount recycled where the definition could be extended to symbiosis efforts.

Total Waste sent to Landfill This indicator is a sub-calculation of the non-hazardous waste destination but specifically addresses the burden on landfill facilities caused by a site. Landfill usage can also have additional impacts on the health and safety of neighbouring residents in addition to local ecosystems which warrants its inclusion as a separate indicator and should be reported in ktonnes.

GHG Emissions As Greenhouse Gas (GHG) emissions are a major concern and are one focal point of expected legislative changes, two indicators are suggested for accounting. Both indicators are following G4-EN15 (Initiative, 2015) and address both the total emissions and the specific emissions for a product. The first indicator is a measurement of the absolute measurement of the GHG emissions in Mtonnes CO_2 eq, while the second is this absolute emission divided by the mass of product resulting from these emissions, expressed as kg CO_2 eq / $kg_{product}$. The two methods account for both the total emissions burden and the specific emissions related to the production of the plant. The latter also relates to the GHG intensity of a product which allows for simple comparison of GHG emissions across all sectors.

3.6.3 Material flow analysis environmental indicators

Material flow analysis is a methodology which is specifically refined for attributing products to its constituent flows. Sendra et al. Suggested an adaptation to the commonly-practiced methodology for specific use in industrial settings (Sendra et al., 2007). A subset of the indicators proposed by Sendra are suggested as potential indicators for EPOS.

Total waste generation (TWG) The TWG indicator exhibits the burden on the environment to treat waste generated by site operations. This indicator specifically refers to the waste generated which is not emitted to air or in wastewater (Sendra et al., 2007) and thus those flows should be accounted for separately. The theory for this indicator is derived from material flow analysis (MFA) and accounts only for the outputs to nature, not including product exports, material recycled or emissions to air or wastewater.

Total Material Requirement The total material requirement is defined by Sendra et al. (Sendra et al., 2007) according to MFA as the direct material input plus unused domestic extraction and indirect flows stemming from imports. This can be viewed as being one step beyond the site boundary, accounting for some indirect consequences of material use. One method of normalising TMR is to view it with respect to the number of workers on a site instead of per mass of production. Normalising in this way leads to another indicator, known as TMRw, which is the total material requirement divided by the number of workers. The use of TMR can also lead to the definition of Eco-Efficiency and Eco-Intensity.

Eco-Efficiency The Eco-Efficiency indicator stems from MFA and is simply a ratio of the annual plant production to the TMR. The mass of product exported is simply divided by the TMR to obtain this ratio and speaks to the mass efficiency of converting feedstock to products.

Eco-Intensity The Eco-Intensity indicator is the inverse of Eco-Efficiency but can be more meaningful in some cases as it is the expression of how much material must be used to produce a reference unit of product. The colloquial analogue can be found in vehicle fuel efficiency where 'miles/gallon$_{\text{fuel}}$' and 'L_{fuel}/100km' are both meaningful quantities but importance placed either on the fuel consumption or the distance travelled as the reference unit.

Material Inefficiency This indicator is a combination of many flows represented in the methodology of MFA presented by Sendra et al. (Sendra et al., 2007). This indicator is calculated by adding the emissions to air and wastewater to the TWG to find the total output to nature and then dividing the sum by the TMR:

$$M_{Inef} = \frac{TWG + \sum \dot{m}^{air}_{emissions} + \sum \dot{m}^{wastewater}_{emissions}}{TMR} \quad (6)$$

The result is fractional, complementary to Eco-Efficiency.

3.7 Summary

Thus, it can be seen that many KPIs can be found in literature and in many cases overlap with those proposed and used by industry while there are also sector-specific KPIs which are not addressed. Gathering sufficient data and calculating all KPIs for industrial sites is often not practical and thus the list of KPIs must be refined for the context in which they will be used. In context of the EPOS project, focused on industrial symbiosis, the list of KPIs will be reduced to a shorter list which is more pragmatic and practical for assessing symbiosis options across sectors.

4 Refinement method

The long list of KPIs that above are refined with multiple steps using different methods in each step. The details of the methods employed are explained in the following sections. The first step for refining the list was a coarse reduction of the longlist of KPIs by the universities, assessing the inputs from each sector as well as the available literature.

This step included analysing the sector-specific and cross-sectoral KPIs to find the commonalities between industries and also between literature sources and industries. Then the KPIs were sorted with respect to the number of sectors using them. The importance of this step is to eliminate the KPIs that are not of importance to any of the EPOS sectors so that more detailed analysis can be carried out using those remaining.

4.1 SPQR Method for Non-Technical KPIs

For the evaluation and selection of non-technical KPIs, the SPQR method was developed and used by EPFL. This method is similar to the RACER method (SEC(2009) (92), 2009) which has been used in other EU projects (Wiedmann et al., 2009). With the RACER method, evaluation is done considering 5 aspects, namely Relevant, Accepted, Credible, Easy and Robust. Since the focus in the EPOS project is on industrial symbiosis, it was necessary to focus on KPIs which adhere to slightly different criteria.

With the SPQR method, the KPIs are evaluated considering 4 independent aspects:

Simple: if it is simple to assess and understand

Predictable: if it is possible to roughly estimate the changes in the KPI, especially how symbiosis will affect it

Quantifiable: if it is possible to express the corresponding KPI in numbers

Relevant: if it is directly or indirectly related to industrial symbiosis and hence EPOS

The following grades are used in the evaluation:

2 : yes

1 : somewhat

0 : no

If 'Land Use' of an industrial unit is considered as an example:

S: 2, as it is simple to assess regardless of the position of the person, whether they work on the unit or not

P: 2, as it is predictable for a size of equipment required to implement a synergy

Q: 2, as it is quantifiable (actual surface area of land)

R: 2, as it is relevant to industrial symbiosis, since considering a potential symbiosis with the unit depends on availability and usage of land for new units or transportation processes

The SPQR evaluation of all the non-technical KPIs can be seen in Table 11.

Table 11: SPQR evaluation of non-technical KPIs

KPI	**S**	**P**	**Q**	**R**
Jobs created	2	1	2	2
Environmental regulatory non-compliances resulting in fines or prosecutions	2	1	2	1
Environmental licence limit exceedances & other non-compliances	0	1	2	1
Fatalities (employees only)	2	0	2	2
Lost Time Injury (employees only)	2	0	2	2
Average hours of training per year per employee per category	1	1	2	1
Leadership positions held by women	2	0	2	0
ISO certifications (140001 etc)	2	0	2	0
Land use	2	2	2	2
Job security	1	0	0	1
Skill level	0	0	1	1
Health and well-being	1	0	1	1
Community stability	0	0	0	0
Education standards	1	0	2	0
Level of community services	1	2	0	2
Crime rates	2	0	2	0
Aesthetic and visual	2	0	1	1
Noise	2	1	2	1
Dust	2	1	2	1
Odour	2	1	1	1

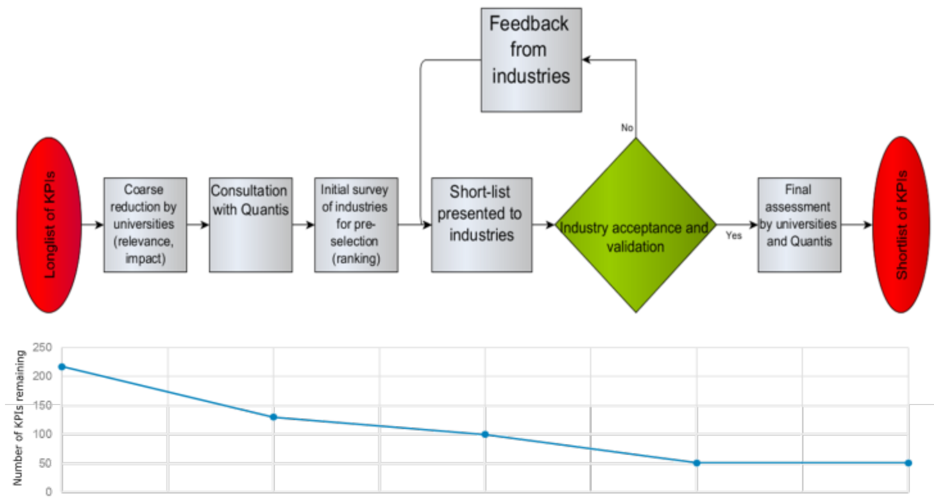

Figure 1: Workflow for KPI list refinement

4.2 Consultation Method

The consultation method was to simply refine the long list of KPIs with respect to the feedback from the project partners. In a technical meeting of project partners, the long list of KPIs was shortened after open discussion with the participation of all partners in the project consortium.

The KPIs in the shortened list were refined by the partners who have expertise in the corresponding field; feedback was received from Quantis on environmental KPIs and UGent on non-technical KPIs.

All the EPOS industries gave feedback on the refined list of KPIs to EPFL as well to make sure that the list includes everything of their interest. Then the final approval was given by discussion between universities and Quantis.

The workflow described in this section is summarized in Figure 1. The reduction in the number of KPIs after each step is also visualised.

5 Shortlist

According to the feedback received on the long-list of KPIs, a shortlist was created, which will be the list of KPIs to be assessed and addressed in the EPOS toolbox. The shortlist of KPIs is presented in Table 12. EPOS aims at a single and simple tool for identifying and encouraging industrial symbiosis; therefore, the list of KPIs are general and cross-sectoral. Industry-specific KPIs were considered in the construction of this list, and commonalities between various sectors were identified in several areas; however, to achieve the ultimate objective of a generic and replicable method and toolbox for industrial symbiosis the sectoral KPIs were not included in the shortlist presented here.

Integration of the KPIs into the toolbox was completed in two ways, separated into two large groups of those which were simple, predictable, quantifiable and relevant and those which lack in one or more aspects. The nomenclature of these two groups are defined as 'direct' KPIs for the first group and 'indirect' KPIs for the second group which links with their usage in the toolbox as described in other project documents. The technical KPIs, those which are often used as metrics in assessing projects or opportunities, often appear in the former group while the non-technical KPIs dominate the latter. Both groups of KPIs are included in the

Table 12: Preliminary shortlist of KPIs

Type	KPI Name	Unit	Source
Legal	Legal Feasibility	LESTS score	
Economic	Profit	€	(Kurup et al., 2005)
	Tangible environmental costs	€	(Kurup et al., 2005)
	Return on Investment	%	(Kimmel et al., 2013)
	Internal rate of return	%	(Kimmel et al., 2013)
	Payback period	years	(Kimmel et al., 2013)
	Operating cost	€/year	
	Investment cost	€	
	Total cost	€/year	
	Total cost with impact	(€+kg)/year	
	Economic Feasibility	LESTS score	
Spatial	Spatial Feasibility	LESTS score	
Technical	Domestic Material Input DMI	t	(Sendra et al., 2007)
	Total Water Input TWI	t	(Sendra et al., 2007)
	Total WasteWater Generated TWWG	t	(Sendra et al., 2007)
	Energy Intensity E-In	GJ/t	(Sendra et al., 2007)
	Energy efficiency	%	
	Exergy efficiency	%	
	Material efficiency	%	
	Technical feasibility	LESTS score	
Social	Social acceptance	LESTS score	
	Number of jobs	number	
Environmental	Direct GHG emissions	M t CO_2eq —kg CO_2eq/ $t_{product}$	(Initiative, 2015)
	Carcinogens	kg C_2H_3Cl eq	(Jolliet et al., 2003)
	Non-carcinogens	kg C_2H_3Cl eq	(Jolliet et al., 2003)
	Respiratory inorganics	kg $PM_{2.5}$ eq	(Jolliet et al., 2003; IMPACT World+, 2012)
	Ionising radiation	Bq	(Jolliet et al., 2003; IMPACT World+, 2012)
	Ozone layer depletion	kg CFC-11 eq	(Jolliet et al., 2003; IMPACT World+, 2012)
	Respiratory organics	kg C_2H_4 eq	(Jolliet et al., 2003)
	Aquatic ecotoxicity	kg TEG water	(Jolliet et al., 2003)
	Terrestrial ecotoxicity	kg TEG soil	(Jolliet et al., 2003)
	Terrestrial acidification/nutrification	kg SO_2 eq	(Jolliet et al., 2003; IMPACT World+, 2012)
	Land occupation	m^2org arable	(Jolliet et al., 2003)
	Aquatic acidification	kg SO_2 eq	(Jolliet et al., 2003)
	Aquatic eutrophication	kg $PO_4{}^{3-}$ (P-limiting)	(Jolliet et al., 2003)
	Global warming	kg CO_2 eq	(Jolliet et al., 2003; IMPACT World+, 2012)
	Non-renewable energy	MJ primary	(Jolliet et al., 2003)
	Mineral extraction	MJ surplus	(Jolliet et al., 2003)
	Human health	DALY	(Jolliet et al., 2003; IMPACT World+, 2012)
	Ecosystem quality	PDF m^2 yr	(Jolliet et al., 2003; IMPACT World+, 2012)
	Climate change	kg CO_2 eq	(Jolliet et al., 2003)
	Resources	MJ primary	(Jolliet et al., 2003)

toolbox, though they are applied and treated in different ways. The indirect KPIs are also used to frame and constrain the problem and this interaction is detailed further in other project documents.

Direct KPIs are those which can be used in the objective function of the optimisation problem. They are termed to be 'direct' as they are linked to the objective function of the optimisation and thus have a direct impact on the solutions found within the solution space. For example, in a situation where investment is required for a symbiosis opportunity, there could be direct links to the net present value, energy efficiency, specific greenhouse gas emissions, number of jobs created and others.

Indirect KPIs are used to constrain and shape the solution space for the optimisation and thus do not directly affect the objective function or its value. These KPIs are relevant and useful for this purpose, thereby confining the solution space. This reduces the requirement for additional iterations to impose scenario-specific constraints for the potential symbiosis project. For example, the social acceptance KPI sets the framework of the project within the local context of the site and the opinions of surrounding communities. This framing of the problem can therefore exclude such possibilities which would be sure to face opposition by the surrounding community actors such as pipeline or stack construction in certain communities.

5.1 Direct KPIs

5.1.1 Economic

Operating Cost The operating cost objective is often used to find the most resource-efficient solutions for design or operation of a plant with specific outputs. When using this KPI as an objective function for optimisation, the solutions tend to focus on matching the requirements as closely as possible with the supply using the least-cost options to provide these services. Since investment cost is not included, favourable levels of operating cost can also correspond to large investment costs or the use of technologies which supply the process requirements in a very efficient way. The operating cost is calculated as the sum of all material and energy (s) inputs multiplied by their specific costs:

$$C^{op} = \sum_{s} Cost_s Flow_s \tag{7}$$

Investment cost The investment cost is used as an objective function to find the least costly option to attain certain goals. In the context of plant retrofits, this could be to identify the least costly option to limit emissions to a certain level or to provide another service at minimum cost. Such additional considerations are required when using this objective function as the investment cost for maintaining the status quo is zero. Optimisation results will therefore converge to this solution as it will always minimum of an optimisation problem where the variables are constrained to be non-negative. Generally, the investment cost is calculated as the summation of all purchase and installation costs of units (u) for modifying a process as in Eq. 8.

$$C^{inv} = \sum_{u} Cost_u Flow_u \tag{8}$$

In the EPOS toolbox, the investment cost is calculated using the fixed and variable investment costs for a unit, multiplied by their load factor as expressed by Eq. 9.

$$C^{inv} = \sum_{u} Cost_u^{fixed} + Cost_u^{variable} Capacity_u \tag{9}$$

Total cost Total cost is the combination of investment cost and operating cost on an annualised basis and therefore provides a balance between installation/retrofits and the reduced operating cost which would be realised from such modifications. This KPI is particularly useful when considering options which have non-zero investment costs and an obvious operational benefit. This KPI permits the optimal cost calculation considering set economic parameters of interest rate for financial instruments and the lifetime of the potential equipment. The total cost is calculated according to Eq. 12 assuming appropriate values for the lifetime (n) of the project and the discount rate (i) for Eq. 11.

$$C^{tot} = F_a C^{inv} + C^{op} \tag{10}$$

Where:

$$F_a = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{11}$$

Total cost with impact This is a sum of the total cost KPI with a monetised value of the impact stemming from a particular emission. Emissions or impacts which can be monetised in this way can therefore be directly added as a cost, such as a tax for CO_2, SO_x, NO_x or landfill waste. Caution is advised for emissions or impacts which do not have a direct monetary impact such as emissions of ozone depleting substances, eutrophying/nutrifying material, radiation or many others. The calculation of total cost with impact is therefore similar to that for total cost with an additional term considered as part of the operating cost to reflect the cost of the impact.

$$C^{tot+imp} = F_a C^{inv} + C^{op} + \sum_e Cost_e Production_e \tag{12}$$

Profit This indicator is listed in (Kimmel et al., 2013) as a publicised indicator for economic impact of industrial symbiosis projects. Profit, also referred to as ‘net income’, is equal to a company’s total revenues minus total expenses over a period of time (typically a year). This value should be reported in the company’s income statement. Total revenues include the amount of any assets (usually cash or accounts receivable) received from customers on the sale of goods or services. Total expenses (or expenditures) are all the outflow of assets from the company to any other entity. Similarly to sales, the perimeter for which the profit is considered should be limited to the site considered for the industrial symbiosis study, rather than the whole company. Therefore, earnings collected at the company scale (e.g. dividends) rather than at the site level should not be considered. Profit can therefore be calculated according to Eq. 13.

$$profit = \sum_p Price_p Production_p \tag{13}$$

Tangible environmental costs This indicator is again listed in (Kurup et al., 2005) as a publicised indicator for economic impact of industrial symbiosis projects. Tangible costs, as opposed to intangible costs, are costs related to an identifiable source or asset and are therefore easily measurable. In the case of environmental tangible costs, this could correspond to a fine that the company would have to pay if the emissions of a given pollutant are higher than the regulatory threshold. For information, the intangible cost associated could be the loss incurred by the reduced health of employees and thus taking more ’illness’ days off or the gradual or immaterial damage to the environment caused by the exposure. A list of tangible environmental costs needs to be defined, including things such as fines for not respecting regulations, environmental taxes, emissions trading schemes, investments made to reduce environmental impact, campaigns to promote eco-friendly behaviour, etc. This is similar to the environmental cost portion of the Total cost with emissions objective but neglecting non-environmental costs as shown in Eq. 14.

$$C^e = \sum_e Cost_e Production_e \tag{14}$$

Return on investment Return on investment (ROI) is a performance measure to evaluate the efficiency of an investment. It measures the amount of financial return on an investment relative to the investment's cost. The formula for this KPI was presented previously as Eq. 1. The gain from investment could also be associated with the savings incurred from buying infrastructure enabling industrial symbiosis actions. For example, the investment could be a pipe which allows sending excess steam from one company to another, which would have otherwise been lost. The gain (for the overall system consisting of both companies) would be the total fuel savings associated to the production of the exchanged steam. More information can be found in (Kimmel et al., 2013).

Internal rate of return Internal rate of return (IRR) is the discount rate that makes the net present value of a particular project equal to zero over the project lifetime. The higher a project's internal rate of return, the more desirable it is to undertake the project. IRR is uniform for investments of varying types and, as such, it can be used to rank multiple prospective projects on a relatively even basis. Assuming the investment costs of various projects are equal, the project with the highest IRR would probably be considered the best from an economic point of view. More information can be found in (Kimmel et al., 2013). The net present value calculation is presented as Eq. 15 and thus the equation must be solved for the discount rate such that NPV=0.

$$NPV = \sum_{t=1}^{N_t} \frac{C_t}{(1+r)^t} - C_0 \tag{15}$$

Where: $\mathrm{C_t}$is the net cash inflow (revenue-expenses) during period t $\mathrm{C_0}$ is the total initial investment cost r is the discount rate t is the time period $\mathrm{N_t}$ is the number of time periods

Payback period The payback period (PBP) is the length of time required to recover the cost of an investment. It is calculated by dividing the initial investment by the yearly cash inflow. The payback period is an important determinant of whether to undertake the project or investment, as longer payback periods are less desirable. The payback period ignores the time value of money, unlike other methods of capital budgeting such as net present value or internal rate of return. More information can be found in (Kimmel et al., 2013). This can be expressed mathematically as in Eq. 16.

$$PBP = \frac{Investment\,cost}{Operational\,benefit} \tag{16}$$

5.1.2 Technical

Domestic Material Input (DMI) The DMI is an indicator derived from material flow analysis (MFA) and is the measure of material flows to be used in the system. The materials used in the system can be domestic (i.e. from own sources) and/or imported. Hence DMI is the sum of domestic extraction and imports. It is used to indicate the material requirement of a system as well as to reflect co-product exchange between sub-systems (Sendra et al., 2007).The DMI of a system can be improved by increasing exchange between the subsystems while the DMI of the subsystems will remain the same. As DMI is directly linked to the size of the system, for comparing two or more systems, normalisation with another parameter which is linked to the system size is required. Eq. 17 shows the calculation of DMI.

$$DMI = \sum_{s} DomesticFlow_s DomesticFlow_s \tag{17}$$

Total water input (TWI) Total water consumption of a system can be represented with TWI. Water usage can be from domestic sources or imported from outside sources such as city water networks, lakes and rivers. It is important to note that natural water sources such as lakes and rivers do not fall in the category of domestic sources as they generally cross the system boundaries and are shared with other systems (Sendra et al., 2007). Domestic sources, therefore, include only water coming from rain or use of water from a surface source on-site or reclaimed at the site. The TWI is a sum from all sources. The total water input is thus expressed by Eq. 18 where w is an index of water flows.

$$TWI = \sum_{w} Water_w \tag{18}$$

Total wastewater generated (TWWG) The TWWG is the total wastewater that is generated by processes in the system under consideration. TWI and TWWG are often similar as the water input is often used as production support and thus rejected after serving its purpose; therefore, higher TWI leads to more TWWG (Sendra et al., 2007). For systems with dissipative usage of water (e.g. evaporation processes), or inclusion of water in the final product, TWI is higher than TWWG. The equation for calculating TWWG is simply a summation of all wastewater generation in the plant as shown in Eq. 19.

$$TWWG = \sum_{w} Water_w^{waste} \tag{19}$$

Energy Intensity (E-In) As the total energy input for a process is directly linked to the production rate of a system, it is difficult to use as a comparative indicator between systems with differing products. The E-In, therefore, is used to indicate the specific energy required for a unit of product. It is calculated by dividing the total energy input by production to obtain the result in units of GJ/tonne as shown in Eq. 20.

$$E - In = \frac{Energy\, used}{Product\, output} \tag{20}$$

Energy Efficiency Energy efficiency is, in general, referred to as the ratio of output energy to input energy. It can be defined for a process, equipment, cycle etc. Therefore, when calculating energy efficiency, the choice of system boundaries is important as the inputs and outputs are determined based on them. Energy efficiency can also be referred to as 'thermal efficiency' or 'first law efficiency' and can also be estimated using losses when the output energy is not measured or more difficult to obtain accurately. This is expressed as shown in Eq. 4.

Exergy efficiency Exergy is defined as the maximum work that can be achieved by a material by reversible exchanges with the environment (Borgnakke et al., 2009). Exergy efficiency is the ratio of output exergy from a system to input exergy to the system. It can be referred to as 'second law efficiency' as well. This is expressed similarly to energy efficiency, where B represents exergy as described by Eq. 5.

Material Efficiency Material efficiency has multiple definitions. It can be referred to as the ratio of material flows that are used in the processes to the total material flow to the system. Alternatively, it may be referred to as the ratio of product flows to raw material flows. The latter method is selected for use in EPOS to reflect opportunities for industries to reduce their overall consumption of material relative to the production rate. This KPI is calculated as shown by Eq. 22.

$$\eta_M = \frac{\dot{m}_{out}^{product}}{\dot{m}_{in}^{feedstock}} = 1 - \frac{\sum \dot{m}_{waste}}{\dot{m}_{in}^{feedstock}} \tag{21}$$

5.1.3 Social

Job creation The number of jobs created is typically a function of the investment cost (for construction, machining, installation, piping and electrical work) or operating cost (for operating and maintaining the equipment/plant). Job creation can also be considered by the skill level requirements of the employees though the total figure is more commonly used as an indicator. Fixed capital accounts for 85 - 90% of total capital and is defined as the total cost of processing installations, buildings, auxiliary services, and engineering involved in the creation of a new plant or significant modification. Peters and Timmerhaus (Peters et al., 2003) also provide cost ranges for labour and Eurostat data (Eurostat, 2017) yields an estimate on wages paid for different occupations, which is then augmented by non-wage employment costs to yield the final employment cost. For the KPI of job creation in EPOS, the parameters in Table 13 are used within the calculation to provide an estimate of the job creation.

Table 13: Range of factors for various plant construction costs and the wage rate

Component	**Factor (% of fixed capital investment)** (Peters et al., 2003)	**European average wage/month [€/m]**	**European average wage/annum[€/yr]**
Engineering & supervision	7.3	8100	97000 (Eurostat, 2017)
Construction expense	9.2	5500	65500 (noa)
Contractor's fee	1.8	5500	65500 (noa)

One full-time employee is considered to be employed for 250 days/annum and the wages per month and per annum are shown in Table 13. Using the method of economic analysis for chemical engineering process design (Peters et al., 2003; Ulrich, 1984; Turton et al., 2008), the annual job creation is calculated as the factor for labour in the construction multiplied by the appropriate factor and divided by the wages for workers of the different skill levels. Similarly, the operating cost is used to calculate the continuing jobs each year considering the factor for running and operating the equipment. By default, European average wages are used for this calculation.

$$N_{jobs} = \sum_i \frac{L_i}{W_i} \left(\frac{Fixed\,capital\,investment}{Lifetime} + 0.11 \cdot Operating\,Cost \right) \tag{22}$$

5.2 Environmental

Environmental KPIs were described in Section 3.6. Quantifying environmental KPIs without excessive data collection naturally leads to the use of existing LCI databases and therefore the selection of LCA KPIs for use in this type of assessment. The IMPACT 2002+ method was selected specifically based on the fact that IMPACT World+ is not currently implemented by the most well-known LCI database provider, ecoinvent. When the IMPACT World+ method becomes available from the ecoinvent centre, the decision will be revisited. Thus, the impact categories in the IMPACT 2002+ method are selected for use but will not be explained again in this section.

5.3 Indirect KPIs

5.3.1 Legal Feasibility

The legal feasibility of a potential symbiosis is assessed by means of a questionnaire directed to one or both of the parties intended to engage in the activity. This is indicated by several factors related to contractual obligations and permitting according to the specific jurisdiction appropriate for the exchange. The specifics for the calculation of this indirect KPI are detailed in other EPOS project documents.

5.3.2 Economic Feasibility

Restrictions on investment or other economic constraints may be applied beyond the standard requirements for meeting certain financial KPIs such as payback period or IRR of a project. The economic feasibility is assessed within this framework in the form of a survey which elucidates the complex decision-making processes which concern whether or not projects are considered to be economically feasible. This has been simplified in EPOS to include the primary impediment to project approval which is the availability of funds for efficiency projects.

5.3.3 Spatial Feasibility

The spatial feasibility of a potential symbiosis is proposed to incorporate two factors which are important: the appreciated distance and the availability of land area for installing new technologies in the case that such modifications are required. The appreciated distance refers to whether a transportation medium already exists or ease of making a connection for solutions which require it. Scores in both categories (when applicable) define the spatial feasibility of the symbiosis opportunity for the identified partners. The questionnaire for determining these scores is included in other EPOS project documents.

5.3.4 Technical Feasibility

The technical feasibility for a project is determined according to a questionnaire designed to assess the ease of making connections between certain material or energy streams which are produced, consumed or converted by two or more industries. The details of the method are more fully described in other EPOS project documents, the summary of which is that the ability of a stream to satisfy the requirements of the process must be assessed, the readiness of technology for any required conversions must be accounted for and whether a symbiosis solution can be implemented by the actors involved.

5.3.5 Social Acceptance

Social acceptance is used as an indicator of whether the project will encounter opposition from local communities, governments or the partners identified for the symbiosis opportunity. The social acceptance is gauged by invoking a questionnaire built on the LESTS methodology which focuses on the degree of cooperation between partners and/or their willingness to cooperate as well as regional specificities related to the community and government. More information can be found in other EPOS project documents regarding the non-technical methodology.

6 Conclusion

This deliverable summarises the effort to gather relevant sectoral KPIs, those available from literature, and refine the list to determine which are the most important and relevant indicators to measure the results of potential industrial symbiosis. Collaboration within the consortium to include feedback from the university partners, Quantis and the participating large industries led to a large reduction in KPIs from the long list to the short list of indicators. The shortlist presented herein has been verified by the consortium but further modifications may evolve as the project enters the second half of its mandate.

The LESTS domains as well as KPIs specific to environmental impact are included in the shortlist which makes it the most robust and comprehensive system of metrics for assessing symbiosis. The valuable feedback from the implementation partners of symbiosis options will contribute to a refined set of solutions which target the most relevant challenges for European industries which includes many factors which are conventionally neglected in the area of process integration and industrial symbiosis.

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