FISSAC

FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN

Industrial Symbiosis Indicators

August 2016

D1.6: Industrial Symbiosis Indicators

WP 1, T 1.4

Authors: Ozge Yilmaz (EKO); Emre Yontem (EKO), Emrah Alkaya (EKO)

H2020-WASTE-2014-two-stage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 642154.

Technical References

Project Acronym	FISSAC
Project Title	FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN
Number	642154
Start date	01/09/2015
End date	29/02/2020

Deliverable No.	D1.6: Industrial Symbiosis Indicators
Dissemination level [11]	PU
Work Package	WP 1 – FROM CURRENT MODELSW OF INDUSTRIAL SYMBIOSIS TO A NEW MODEL
Task	T 1.4 – Identification and development of ecoinnovation, waste and IS indicators
Lead beneficiary	EKO
Contributing beneficiary(ies)	ACC, AKG, BEF, CBI, CSM, FAB, FER, GTS, KER, TCM, TEC, RIN, VAN, DAP, SP, TRI, ACR
Due date of deliverable	31 August 2016
Actual submission date	15 September 2016

Document history

V	Date	Beneficiary	Author
1	20/07/2016	EKO DAPP SP RINA TCM	Özge Yılmaz, Emrah Alkaya Carlo Strazza, Carlo Barbieri Lisa Bolin Felice Alfieri, Francesca Massone Aslı Kesim
2	18/8/2016	EKO	Özge Yılmaz, Emrah Alkaya
3	9/9/2016	EKO ACC	Özge Yılmaz, Emrah Alkaya, Emre Yöntem Blanca Juez Sanchez
4	12/9/2016	EKO	Özge Yılmaz, Emrah Alkaya, Emre Yöntem
5	12/9/2016	EKO	Özge Yılmaz, Emrah Alkaya, Emre Yöntem

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

Summary

This deliverable is prepared under the FISSAC Project as an output of Task 1.4: Identification and development of ecoinnovation, waste and IS indicators. Submission of this report along with the deliverable titled “D1.5: Assessment of BAT and emerging techniques to facilitate the collaboration across sectors” mark the successful completion of **“Milestone 3: Best Available Techniques evaluated and IS indicators defined” of the FISSAC Project.**

Objective of this deliverable is to

(i) provide an overview of existing environmental, economic and social indicators in use by the European Union (EU) and other international organizations,
(ii) establish a scope and a methodology for selection of indicators in relevance to FISSAC Project,
(iii) deliver the list of indicators selected under Task 1.4 activities,
(iv) elaborate indicator definitions (when necessary) and their relevance to existing indicator sets, and

Various indicator categories including IS indicators, circularity indicators, eco-innovation indicators, resource efficiency indicators, sustainability indicators, and network strength analysis indicators were evaluated. The proposed list of indicators entail basic environmental, economic and social indicators, LCA indicators, circularity indicators and indicators on network strength analysis. The list has been compiled after a detailed literature review on existing indicators used within the EU and available indicators in peer-reviewed articles. Following the compilation of a preliminary indicator list based on the literature review, the proposed list has been finalized with the contributions of all participants of the Task. Evaluation of the selected FISSAC IS indicator set has been made in terms of methods of quantification, applicability, special provisions for use and their relation with the existing indicator sets. As a result, the indicator list proposed in this report should be regarded as a compilation of possible relevant metrics, which will be used and evaluated through the course of the Project, in particular in life cycle assessment, eco-design and ETV tasks. Furthermore, as the studies on technical aspects of valorisation of SRMs under FISSAC scheme progresses, indicators may be prioritised or composite indicators may be added. With the feedback received in these tasks, the indicator list will be incorporated into the FISSAC IS Platform. The FISSAC ICT Platform is expected to be able to allow the use of most of the indicators proposed in this report, which will allow the evaluation of them in the project environmental performance assessments.

The list of proposed indicators are presented in Table 1, which are grouped into environmental, economic, social, circularity and network indicators. Life cycle indicators are handled as a sub-group under environmental indicators. For the purpose of the FISSAC Project, use of basic indicators are proposed to quantify environmental, economic and social aspects while life cycle indicators include composite indicators as well.

Structure of the proposed FISSAC indicator set is comprised of baseline performance indicators which quantify the performance of the IS network in a static manner and impact indicators which quantify the change of performance over time. Both baseline and impact indicators contain absolute and specific indicators, though for impact indicators change in absolute and specific values. All the specific indicators in the report are normalized in terms of unit amount of product, turnover and net value added.

Project funded by the European Union’s
Horizon 2020 research and innovation programme under
grant agreement № 642154.

Table 1 Main indicator groups proposed for monitoring IS initiatives

	Indicators
ENVIRONMENTAL	Material consumption (primary and secondary raw material consumption)
	Energy consumption (fuel, thermal energy, electricity, renewable energy consumption)
	Exergy
	Air emissions (GHG and other emissions)
	Solid waste generation (hazardous and non-hazardous wastes)
	By-products
	Life cycle indicators (resource depletion, carbon/water/ecological footprints, cumulative energy and exergy demand, life cycle cost)
ECONOMIC	Product quantity
	Turnover
	Net value added
	OPEX (material, energy etc. costs, environmental cost savings, revenues from IS activities)
	CAPEX
SOCIAL	Job creation and retention
	Creation of IS
	Social responsibility
	Lifelong learning
	Health and safety at work
	Rate of community participation
	Level of social acceptance
	Community development
	Innovation and investment in R&D
CIRCULARITY	Environmental impact momentum
	Utility (lifetime and function served)
	Environmental cost effectiveness
NSA	Betweenness and closeness
	Reciprocity
	Intensity

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Horizon 2020 research and innovation programme under
grant agreement № 642154.

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Abbreviations and acronyms

BAT:	Best Available Technique
CAPEX:	Capital cost
CSPI:	Composite sustainable development index
DPSIR:	Driver, Pressure, State, Impact, Response (Framework)
EBI:	European Benchmark Indicator
EC:	European Commission
EEA:	European Environment Agency
EF:	Environmental footprint
EHS:	Environmental health and safety
EPR:	Environmental performance review
EPSM:	Environmental performance strategy map
ETV:	Environmental Technology Verification
EU:	European Union
FP:	Framework Programme
GDP:	Gross Domestic Product
GEM:	General environmental management
GHG:	Greenhouse gases
GW:	Groundwater
HFC:	Hydrofluorocarbon
IS:	Industrial symbiosis
KPI:	Key performance indicator
LCA:	Life cycle assessment
LCC:	Life cycle costing
MFA:	Material flow analysis
MIPS:	Material input per unit service
NPV:	Net present value
OPEX:	Operational cost
PFC:	Perfluorocarbon
PRM:	Primary raw material
RM:	Raw material
ROI:	Return on investment
SCP:	Sustainable consumption and production
SDI:	Sustainable development indicators
SDS:	Sustainable development strategy
SEPI:	Sustainable environment performance indicator
SF6:	Sulphur hexafluoride
SI:	Structural indicators
SPI:	Sustainability performance index
SRM:	Secondary raw material
SW:	Surface water
WFD:	Waste Framework Directive

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Horizon 2020 research and innovation programme under
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1 INTRODUCTION

According to Eurostat, an indicator is a "quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions (e.g. of a country) in a given area" [1]. Regular assessment of indicators reveal the direction of change across different units and through time. They serve the purpose of setting policy priorities as well as benchmarking or monitoring performance [1]. Indicators are standardised based on a common denominator so that the data elements are comparable between different systems so that use of this data allows for meaningful comparisons [2]. Indicators can be categorized as basic and composite indicators in the broadest sense where basic indicators describe principal characteristics of environmental performance and a socio-economic phenomenon or process and composite indicators is composed of a set of basic or elementary indicators related to a given phenomenon or process [3] [4]. Furthermore, a statistical indicator can be produced based on other indicators by processing their values according to a specified procedure [5].

In "Task 1.4: Identification and development of ecoinnovation, waste and IS indicators", main aim was to

- Identify and analyse the current qualitative and quantitative indicators for quantifying the environmental, economic and social dimensions of IS initiatives,
- Develop new IS indicators if necessary,
- Provide definitions for the indicators, and
- Enable their integration to the FISSAC Platform.

The indicator-based assessment plays an important part in FISSAC Industrial Symbiosis (IS) Model for establishment and monitoring of IS and stand as a vital component of the FISSAC Platform. The indicator-based assessment methodology to be implemented in the FISSAC Model can defined as the quantification of indicators based on the comparison between before and after implementation of the IS network by means of a reference time frame [6]. Furthermore, comparisons can be made periodically to reveal continuous improvement created by IS in terms of reduced environmental impacts, economic gains of associated companies or progress on social issues. Therefore, baseline for assessment can be set to showcase effects of establishment of the FISSAC IS network or constant progress over the years.

1.1 Objective

Objective of this deliverable is to

(i) provide an overview of existing environmental, economic and social indicators in use by the European Union (EU) and other international organizations,
(ii) establish a scope and a methodology for selection of indicators in relevance to FISSAC Project,
(iii) deliver a proposed list of indicators selected under Task 1.4 activities, and
(iv) elaborate indicator definitions (when necessary) and their relevance to existing indicator sets.

1.2 Scope

The document targets to cover a background assessment on the field, aiming to identify internationally applied and standardised quantification metrics, an in depth analysis of various indicator categories and their use in the environmental performance evaluations and a set of proposed and derived innovative indicators, which have the potential to be used in the project assessments as well as the ICT Platform.

Although the main aim of Task 1.4 is to provide a set of indicators for the FISSAC IS network, within the context of this deliverable, a broader scope was observed in order to deliver an indicator set reusable by other IS initiatives as well. A high number of selected indicators were found to be reusable in IS initiatives other than FISSAC's. From replication stand point, sectorial Key Performance Indicators (KPIs) can be network-specific and should be evaluated on a case-by-case basis depending on the industrial sectors involved in a given IS network.

Various indicator categories including IS indicators, circularity indicators, eco-innovation indicators, resource efficiency indicators, sustainability indicators, and network strength analysis indicators were evaluated. Sectorial KPIs were covered for cement and ceramic industry mainly, as these industries represent the sectors receiving SRM to be incorporated into the manufacturing process. Main reason behind limiting use of sectorial KPIs to SRM receiving sectors is the possibility of modifications necessary for valorisation of SRMs having an effect on a number of process parameters.

To be able to bring a holistic approach to the indicator-based assessment in FISSAC project, indicators addressing environmental, economic and social issues were studied. As some of the FISSAC sectors are considered as material- and energy-intensive, indicators related to material and energy (including fuel) consumption were carefully studied. The proposed list of indicators on these topics aims to enable evaluation of material and energy efficiency in detail. In addition to energy indicators, exergy indicators are also introduced as an important group of indicators to be able to draw conclusions on the quality of energy consumed by the FISSAC network. Maybe to a lower relevance to the FISSAC IS network, water consumption was also covered in this report for the sake of completeness of IS indicators should these be used for evaluating other IS initiatives.

On the output side, essential indicators for air emissions, wastewater generation and solid wastes were included. In terms of air emissions, a special emphasis was made for the greenhouse gas (GHG) emissions since not only these contribute to global climate change issue but also there are serious efforts to reduce carbon emissions in construction value chain and embodied energy of construction materials. Other air emissions were handled through a generic set of indicators however; possible need of disaggregating the indicators in terms of specific air pollutants is underlined. This selection can be made on the basis of commonly used sectorial indicators or based on regulatory obligations of companies for reporting their emissions. As in the case of water consumption, indicators for wastewater generation are provided for the purpose of enabling replicability in other IS networks. Waste heat can also be an important source of resource efficiency. Especially in sectors where thermal processes are employed such as cement and ceramic industries, waste heat generation and possible valorisation techniques can be of concern to companies. For this reason, indicators on waste heat generation were covered in this report.

Indicators for solid waste and by-product both complement each other and the secondary raw material (SRM) related indicators applicable to waste generating sectors (defined as supply-end in an IS network in this report) and SRM utilizing sectors (defined as receiving-end in an IS network in this report) respectively. Companies in FISSAC network are expected to monitor their waste and by-product generation in a periodic manner and in combination with SRM indicators, a better picture can be obtained on overall utilization of by-products or recycling of wastes across the network.

Another important group of environmental indicators, termed as life cycle indicators, aim to go beyond simple input/output quantities and provide an insight on the impacts of consuming the inputs and creating emissions on the environment. These indicators share a similar scope with the environmental indicators based on material and energy flows. For instance, according to the scheme proposed in this report, the quantities of GHG emissions are monitored as a part environmental indicators. In addition to these, global warming potential, which aims to quantify overall GHG emissions from a life cycle point of view.

Economic indicators cover important topics including product quantity, turnover, net value added, as well as operational and capital costs. Among these, the first three can be used as stand-alone indicators or can be used for normalization of other indicators to obtain specific (or intensity) indicators. More detail on normalization can be found in Section 5.2. Operational cost indicators provided in following sections are detailed in terms of common cost items contributing to operational costs. Moreover, possible cost savings created by establishment of the IS initiative are also addressed.

Finally, the range of social indicators included in the proposed list is based on the possible social benefits of IS. Main criteria of selection was the ability to quantify these social aspects as the list of the indicators suggested in this deliverable are mainly limited to quantitative indicators to minimize subjectivity of analysing qualitative aspects.

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Horizon 2020 research and innovation programme under
grant agreement № 642154.

Other indicators studied under Task 1.4 do not fall strictly under the categories of environmental, economic or social indicators. These indicators include circularity indicators and network indicators. These aim to assess how well the IS network is established in terms of network strength and how well the established network responds to "circularity" criteria and needs. Although indicators under abovementioned environmental, economic, and social topics are commonly employed, network and circularity indicators are rather new to the indicator literature. To the best of the knowledge of Project partners, application of some the proposed indicators in FISSAC Project will be among the few examples of application and can be considered as beyond state-of-the-art in indicator based assessment of IS initiatives.

1.3 Outline of the methodology

The activities carried out under Task 1.4 followed the steps below:

1. A detailed literature review on
    1.1. Existing sustainability related indicators used within the EU by different organizations
    1.2. Available indicators used in research on industrial symbiosis, circular economy and production models, sustainable consumption and production, sectorial sustainability and cleaner production practices, and
    1.3. General properties and characteristics of the indicators come across at Step 1.1 and 1.2.
2. Generation of a preliminary FISSAC industrial symbiosis indicator list and selection of indicators upon feedback from Task 1.4 partners.
3. Definition of a methodology for sorting and classifying the selected indicators to provide a simpler grasp on different indicators as well as enhance replicability in other IS initiatives.
4. Evaluation of the selected FISSAC IS indicator set in terms of methods of quantification, applicability, special provisions for use and their relation with the existing indicator sets.

1.4 Positioning of the Report in the FISSAC Project Tasks

Task 1.4, with this report as the main output, plays a central role in the project actions related with the evaluation of the changes provided by the IS.

The preliminary assessment of the Best Available Techniques (BATs) and Material Flow Analysis (MFA) carried out in WP1 provides a baseline for the project works. Thus this baseline will also serve as the benchmarking start point for evaluation of the IS benefits in the project. The indicators identified in this report shall be applied to the studied industrial systems. The material and energy balances for the FISSAC processes are key to quantify a high percentage of the environmental indicators proposed in this report. These indicators mainly monitor the environmental performance of the network through determining change in quantities of either inputs (consumption of raw material, energy, water etc.) or outputs (i.e. emissions). Therefore, the mass balances provided in *D1.5: Assessment of BAT and emerging techniques to facilitate the collaboration across sectors* previously are highly relevant to quantification of indicators proposed in this report at later stages of the Project.

Task 1.4 has close ties with Product Eco-design and Certification activities under WP3. The eco-design and ETV processes utilize a set of environment indicators for establishment of the environmental profile for eco-design and verification of the environmental claim during ETV process. Furthermore, life cycle indicators (i.e. life cycle impact categories) to be used during Life Cycle Assessment (LCA) under WP3 are discussed as a part of the FISSAC indicator set. Evaluation of the environmental indicators proposed in report through MFA can also be carried out as a part of LCA during analysis of life cycle inventory, which is basically material and energy balances laid down for the industrial process for the FISSAC case.

WP6, which aims to deliver an FISSAC ICT platform serving for the assessment and quantification of the results, will be one of the core beneficiaries of this output. The FISSAC platform has the objective to define the baseline and improved IS system components, the material and energy flows among them, collect data from the industrial partners and references, assess and quantify the performances of the solutions. These tasks will be carried out by the platform, with reference to the existing LCA indicators, as well as those proposed in this document. The indicators will be initially analysed, implemented and integrated into the FISSAC platform within the relevant WP6 tasks. This opportunity of developing and utilising new indicators gives the FISSAC project the strength to develop a multi-dimensional and cross sectorial assessment methodology, hence delivering the FISSAC Model.

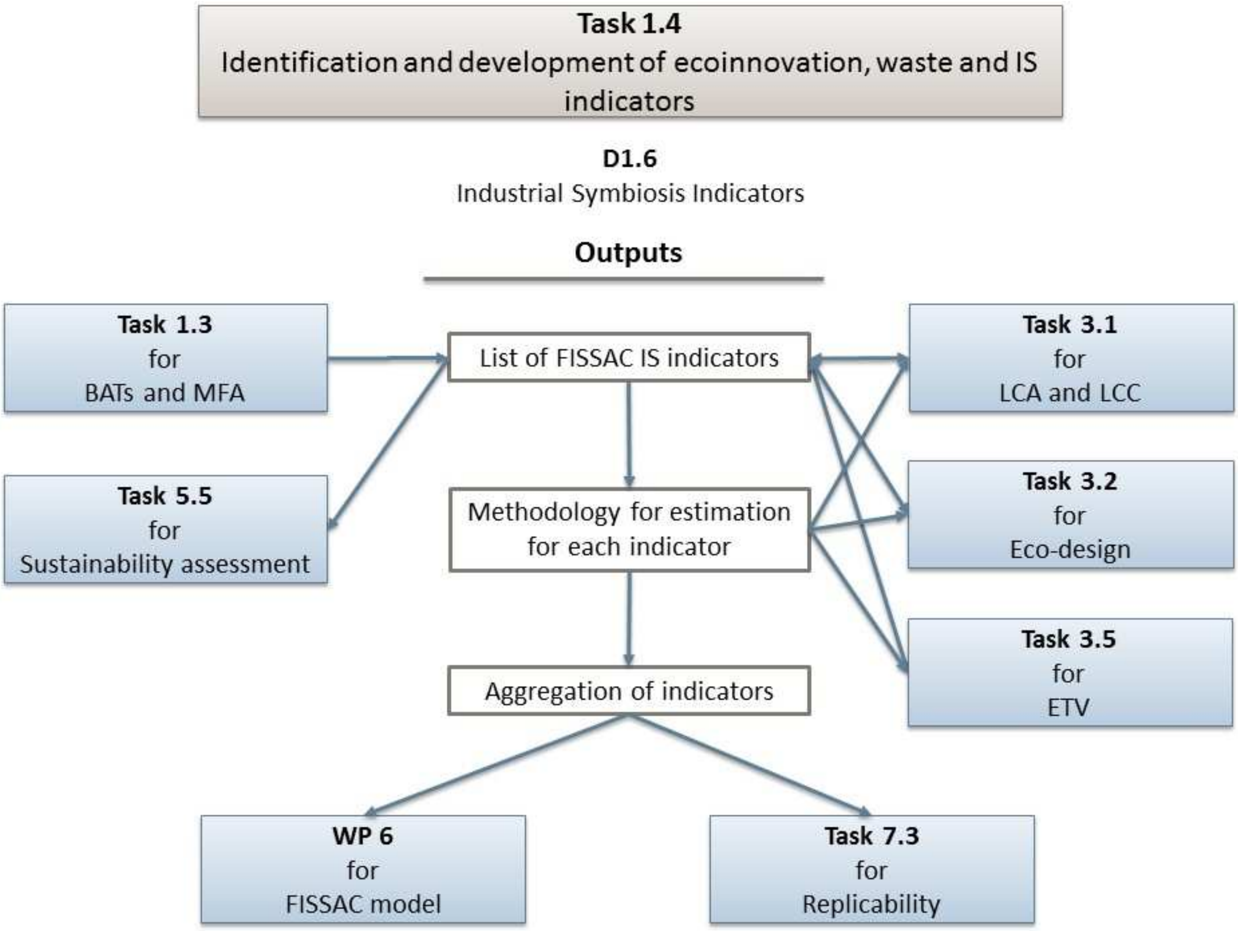

Figure 1 Relation of Task 1.4 with other FISSAC activities

Current report can be considered as a first step of finalization of the indicator-based assessment of the FISSAC IS model. The list of indicators proposed in this report will be further discussed especially under WP3 and WP6. Some adjustments to the list, if deemed necessary, can be made during LCA, eco-design, and ETV activities. Furthermore, during establishment of FISSAC IS model, in particular while developing the FISSAC Platform, the indicator list is expected to be revisited. As the studies on technical aspects of valorisation of SRMs under FISSAC scheme progresses, new indicators may be added or some indicators may be prioritized over others to obtain an even more tailored list of FISSAC IS indicators. In this sense, the reader is urged to consider work on IS indicators as iterative as changes may occur on the final list in the light of forthcoming project activities.

1.4.1 Responsibilities

Activities under Task 1.4 and this deliverable are carried out under the lead of Ekodenge and with the participation of many partners of the FISSAC Project. Responsibilities of the associated partners can be seen in Table 2.

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Table 2 Responsibilities of partners under Task 1.4

Partner	Literature review	Setting indicator structure	Selection of indicators	Compilation of the report
EKO (Task leader)	✓	✓	✓	✓
ACC (WP Leader)			✓	✓
ACR			✓	
AKG			✓	
BGM			✓	
CBI			✓	
CSM			✓	
DAPP	✓	✓	✓	✓
FAB			✓	
FER			✓	
GEO			✓	
GTS			✓	
KER			✓	
RINA	✓		✓	✓
SP			✓	
SYM			✓	
TCM	✓		✓	
TEC			✓	
TRI			✓	
VAN			✓	

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2 BACKGROUND

This section starts with an introduction to general properties of indicators including some basic criteria, which are considered necessary for high quality indicators. Next, an important framework called Driver, Pressure, State, Impact, Response (DPSIR) Framework is introduced due to its importance especially for development of environmental indicators currently under use by different organizations. This Framework is also the basis for many environmental indicators included in this report. As will be seen in Chapter 3, the number of indicators under use is extensive, which makes a selection process necessary. Following introduction of the DPSIR Framework, some remarks on common criteria on selection of which indicators to be used is given. A brief discussion data sources for quantification of indicators are included in order to provide a starting point for the discussion on integration of indicators to FISSAC Platform. Finally, a section is dedicated to the link between indicators and Eco-design and ETV processes since this connection is important for the future work in WP3.

2.1 General properties of the indicators

As mentioned in the Introduction Section, indicators provide insight on change of direction or "a signpost of change" in performance or state of a system based on time-bond data over a chosen period of time [7]. In particular, indicators can help to:

- Measure progress and achievements;
- Clarify consistency between activities, outputs, outcomes and goals;
- Ensure legitimacy and accountability to all stakeholders by demonstrating progress;
- Assess project and staff performance [7].

Whether a basic indicator or a composite one, there are a number of properties proposed for an indicator to serve its purpose of reflecting the domain it is targeted. These so-called indicator criteria are usually abbreviated based on the first letters of the indicator properties they cover.

First of these criteria is called "SMART", which states that the indicators should be **S**pecific, **M**easurable, **A**ttainable, **R**elevant, and **T**ime-bound. In particular:

Specific: When indicators measure what they claim to measure and are not confounded by other factors.

- Is it clear exactly what is being measured? Has the appropriate level of disaggregation been specified?
- Does the indicator capture the essence of the desired result?
- Does it capture differences across areas and categories of people?
- Is the indicator specific enough to measure progress towards the result?

Measurable: Indicators must be precisely defined so that their measurement is unambiguous. This generally means quantitative (percentage, ratio, number), but can also mean qualitative.

- Are changes objectively verifiable?
- Will the indicator show desirable change?
- Is it a reliable and clear measure of results?
- Is it sensitive to changes in policies and programmes?
- Do stakeholders agree on exactly what to measure?

Attainable: The required data can actually be measured and collected.

- What changes are anticipated as a result of the assistance?
- Are the result(s) realistic? For this, a credible link between outputs, contributions of partnerships and outcome is indispensable.

Relevant: The indicators must provide information useful to the programme/project objectives and help guide decisions that key users will need to make.

- Does the indicator capture the essence of the desired result?
- Is it relevant to the intended outputs and outcome?

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- Is the indicator plausibly associated with the sphere of activity?

Time-bound: Indicators should describe when change is expected. An indicator needs to be collected and reported at the right time.

- Are data actually available at reasonable cost and effort?
- Are data sources known?
- Does an indicator monitoring plan exist? [7] [8].

Another acronym recently suggested is "SPICED"; **S**ubjective, **P**articipatory, **I**nterpreted, **C**ommunicable, **E**mpowering and **D**isaggregated. SMART describes the properties of the indicators themselves, while SPICED relates more to how indicators should be used. The SPICED approach puts more emphasis on developing indicators that stakeholders can define and use for their own purposes of interpreting and learning about change, rather than simply measuring or attempting to demonstrate impact to meet requirements [9].

The EC's Impact Assessment Guidelines specify the so-called RACER criteria for useful indicators. It is an evaluation framework developed for assessing the value of scientific tools for use in policy making. RACER is an acronym for:

- **R**elevant = closely linked to the objectives to be reached
- **A**ccepted = by staff, stakeholders, and other users
- **C**redible = accessible to non experts, unambiguous and easy to interpret
- **E**asy = feasible to monitor and collect data at reasonable cost
- **R**obust = not easily manipulated [10].

The RACER Criteria is explained in Figure 2.

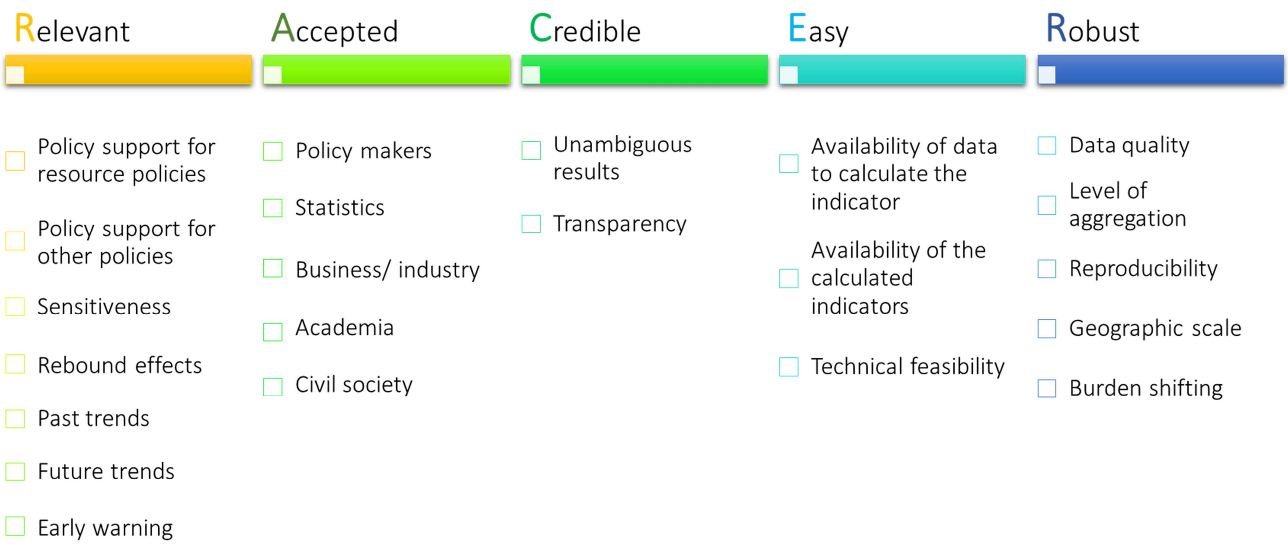

Figure 2 RACER Criteria explained [11]

2.2 Driver, Pressure, State, Impact, Response (DPSIR) Framework

The DPSIR framework, built upon the existing OECD model, is used to classify and structure environmental indicators for policy use and offers a basis for analysing the interrelated factors that impact on the environment [12]. This framework explains the relation between the use of natural resources, its impacts on the natural environment and challenges of resource efficiency (Figure 3).

As the first step, the key drivers for resource use are identified. Next, the type of pressures exerted on the natural resources is described considering the life cycle of the natural environment. The state of the ecosystem providing or sustaining the resources is laid down. The impacts on status of resources and the environment, actual or expected, are assessed based on the pressure exerted by natural resource consumption. Finally, the policy actions such as energy efficiency standards or recycling targets in response to the pressures are described. Based on this assessment framework, resource productivity indicators can be developed from the relation between drivers and pressures. Furthermore, resource specific impacts can be quantified through indicators by considering the relation between pressures and impacts [12].

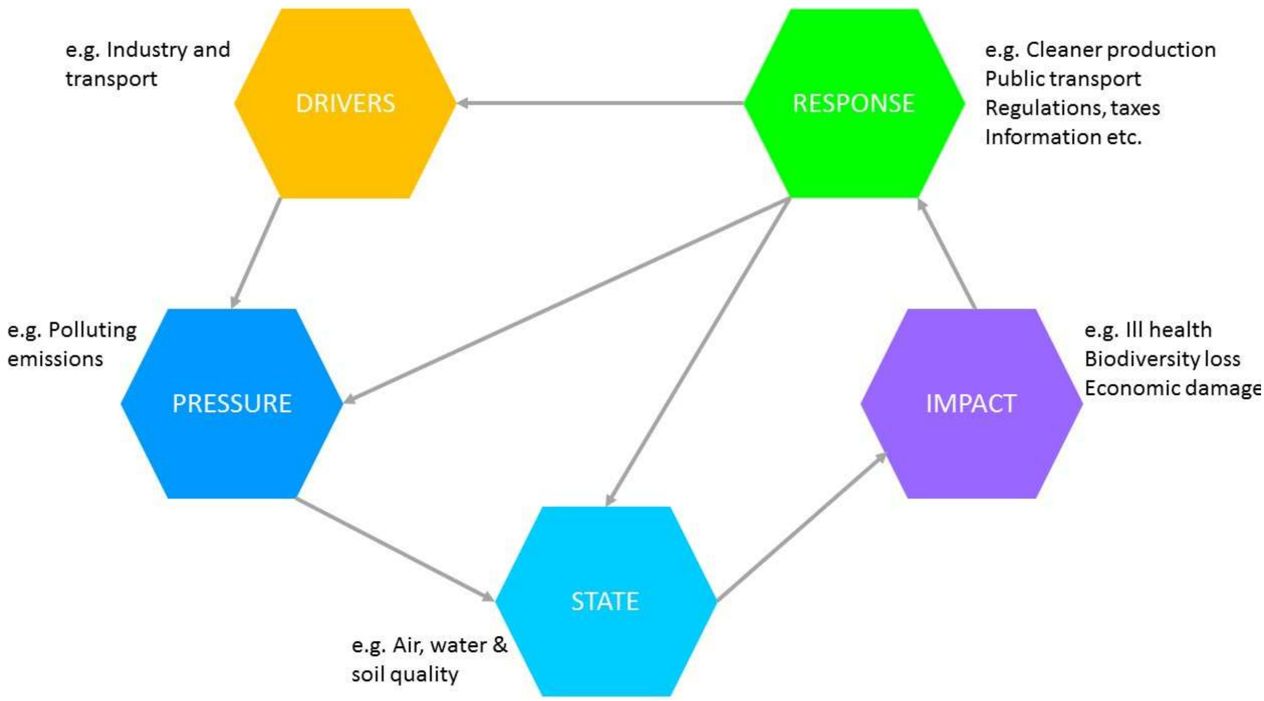

Figure 3 DPSIR Framework [11]

2.3 Criteria for selection of indicators

This section provides examples of criteria use by different organizations to select their indicator sets of choice. The indicators developed based on the DPSIR Framework are expected to fulfil the SMART and RACER Criteria before entering the selection process.

For selection of the indicators the EC used the following criteria:

- Policy relevance
- Coverage of all relevant categories and resources
- Coherence and completeness
- Transparency of trade-offs and negative side effects such as burden shifting
- Link to a timeline for production of the data and calculation of the indicator
- Applicability to different levels of economic activities (EU, Member States, sectors, firms, products)
- Support by data that can be aggregated and disaggregated across scales, from products to sectors to countries [11].

Another set of criteria proposed include:

- Policy relevance
- Easy to communicate
- Directionally safe information
- Consistent and transparent accounting scheme
- Resource use expressed in absolute numbers

- Distinguish between relative and absolute decoupling
- Harmonised database
- Headline indicator comprehensive in categories included
- Headline indicator to find balance between aggregation and disaggregation
- Comprehensive in terms of geographical coverage
- Geographically explicit
- Compatible with the system of national accounts [11].

EEA uses the criteria below for selection of the core indicator set:

1. *Policy relevance*: Relevance to identified objectives in EU and other international policy documents.
2. *Progress towards targets*: When quantitative or qualitative targets linked to objectives have been set in policy documents.
3. *Available and routinely collected data*: Availability of data based on reporting obligations of the signed up countries as well as streamlining of data flows.
4. *Spatial and temporal coverage*: These criteria are based on the actual coverage of reported data compared with the target coverage.
5. *National scale and representativeness of data*: For enabling the benchmarking of countries' performances
6. *Understandability of indicators*: Clear definition of the indicator, appropriate assessment and presentation, avoidance of contradictory messages.
7. *Methodologically well founded:* Clear description of the methodology and formulae used, with appropriate scientific references.
8. *EU priority policy issues*: Applied to ensure that indicators map to priorities for policy and in the EEA management plan. [13].

Table 3 presents the selection criteria for material flow indicators employed by the OECD.

Table 3 Selection criteria for material flow indicators [14]

Policy Relevance and Utility for Users	
A material flow indicator should o Provide a representative picture of material flows and their interactions with the environment and economy. o Be simple, easy to interpret and to be able to show trends over time. o Be responsive to changes in economic activities, resource productivity, technology development and environment. o Have threshold or reference value for comparison including international ones.	Particular aspects to be considered: o The environmental and economic significance of material flow indicators in relation to environmental pressures or impacts as well as economic and trade related issues. o The choice of appropriate reference values to which the indicators can be compared. o The level of aggregation/detail of indicators
Analytical Soundness	
A material flow indicator should o Be theoretically well founded in technical and scientific terms. o Be based on international standards and international consensus about its validity. o Lend itself to being linked to economic and environmental models, forecasting and information systems.	Particular aspects to be considered: o The internal coherence of indicators. o The external coherence of indicators with national accounts aggregates and productivity measures. o The additivity of material flow variables to enable the calculation of regional aggregates.
Measurability	
The data required to support the indicator should be: o Readily accessible or made available at a reasonable cost/benefit ratio o Adequately documented and of know quality o Update at regular intervals in accordance with reliable procedure.	Particular aspects to be considered: o The level of ambition pursued and the choice of the data sources to be used. o Data accuracy (completeness and statistical uncertainties) due to the indirect measurement of certain material flow variables.

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2.4 Data sources for sustainability indicators

Energy, water, and materials represent three standard types of inputs used by most organizations [15].

The Material Flow Analysis (MFA) provides about the physical flows of materials through economies as well as in production systems, which serves as the basis for all material related indicators on resource efficiency and SCP. MFA is a quantitative procedure, which can be utilized at various levels. The accounts provide aggregate an overview of extraction of raw material and quantities of consumption [11].

Resource productivity, material reuse and recycling rate, and the rate of waste for final disposal are the three core sustainability indicators and have been used to address waste and unsustainable consumption issues. MFA has been used as a data source in a number of indicator systems including the European Strategy for Environmental Accounting, Japanese indicators system, and Material Flow Accounts database developed by the Work Resources Institute of the US [11].

Within the scope of the FISSAC Project, MFA methodology will be utilized as the baseline data collection and management methodology for the further quantification of the specified IS indicators and LCA/LCC studies at the life cycle inventory stage.

Similar to material accounting, energy balances, which compile data on all energy products entering, exiting and used within a given system, are used for energy-related indicators. Energy balances are invaluable for calculating efficiencies of transformation processes, as well as relative shares of different sectors or products as well as estimation of greenhouse gas emissions that are emitted in high volumes as a result of processes producing and consuming energy. Both material and energy balances generally take the form of a matrix of products and flows, with varying levels of disaggregation, although graphical formats also exist (e.g. Sankey diagram) [11].

2.5 Link to Eco-design and ETV Processes

2.5.1 Eco-design process

Eco-design is defined as "the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle" [16].

Material consumption is a natural concern of companies, since reducing the inputs of materials also implies reducing the costs of production. In this sense, companies take into account material efficiency in the product design, mostly based on economic reasons.

Eco-design should also include environmental aspects within the understanding of material efficiency. This way, material efficiency would be not only the amount of materials needed to manufacture a product, but also the environmental impacts of those materials. Therefore, increasing material efficiency means to achieve the same service or function within a product (e.g. structure, texture, aspect, insulation) with lower environmental impacts of the materials used [12].

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products establishes a framework for minimum eco-design requirements which goods that consume energy must meet before they can be used or sold in the EU. According to this directive the eco-design process should adopt a cradle-to-grave approach and consider the entire product life cycle [17].

As a part of the environmental product performance policy, the manufacturer must be able to provide a framework for setting and reviewing environmental product performance. All the measures adopted by the manufacturers to improve environmental performance and establish the ecological profile of the product must be substantiated in a systematic manner. For this purpose, eco-efficiency indicators are utilized with a view to improve the overall environmental performance to set up the baseline for comparison and monitor the improvements. These indicators need to consider technological options taking technical and economic requirements into account [12]. These indicators enable the user to verify aspects such as materials and energy consumed, expected emissions and waste as well as the possibility for reuse, recycling and recovery [17].

2.5.2 Environmental Technology Verification (ETV) process

During the Environmental Technology Verification (ETV) Process the definition of the verification parameters is carried out by the Verification Body in co-operation with the proposer, building on the initial performance claim.

The list of verification parameters, also called 'performance claim', shall be set to ensure that the technology is tested for parameters and in ranges that are relevant for the purchasers and users of the technology considering regulatory requirements, intended application based needs, key environmental factors and state of the art performance of technologies performing similar functions.

The list of verification parameters can include:

- **operational parameters** related to the technical conditions of the intended application and to the verification and test conditions; examples of operational parameters include production capacity, maximum temperature and concentrations of non-target compounds in matrix
- **environmental parameters** related to important potential impacts on the environment, directly and indirectly, along the life cycle (including raw materials, production, use, recycling, end-of-life disposal)
- **additional parameters** related to other information about the technology that is useful for users but that may not necessarily be measurable through tests; examples of possible additional parameters include the expected service time during which the claimed performance is respected, overall service life, health and safety issues, installation and maintenance requirements and operating costs.

Verification parameters should take into account not only the technical performance but also the environmental impacts throughout a life cycle and sustainability assessment study. However, the problem of cost-and time-efficient verification impose the use of simplified tools for taking into account an LCA approach in a verification procedure. Parameters to be considered within ETV are listed in Table 4.

Table 4 Parameters to be considered within the ETV process

Emissions / Waste	Consumption	Other characteristics
Air emissions	Water	Longevity
Water emissions	Electricity	Robustness
Waste generated	Raw materials	Reusability, recyclability
Use of hazardous materials	Resources used during production	
Consumables	End of life decommissioning	

A tentative list of indicators applicable in the ETV process can be seen in Table 5.

Table 5 Circular economy indicators applicable in the ETV of FISSAC products

	Description	Formula	Unit	Ref
F_R	Fraction of mass of a product's feedstock from recycled sources		--	
F_U	Fraction of mass of a product's feedstock from reused sources		--	
V	Mass of virgin feedstock used in a product	$V = M(1 - F_R - F_U)$	kg	[18]
E_F	Efficiency of the recycling process used to produce recycled feedstock for a product		%	
W_F	Mass of unrecoverable waste generated when producing recycled feedstock for a product	$W_F = M \frac{(1-E_F)F_R}{E_F}$	kg	[18]
Life cycle	Life Cycle Impact indicators / Carbon Footprint / Water			

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

Indicators	Footprint (usually not included in ETV indicators because too complex… simplified?)			
Embodied energy	Embodied energy is the energy used during the entire life cycle of a product, including its manufacture, transportation, and disposal, as well as the inherent energy captured within the product itself.		MJ/Kg	
Exergy	Exergy is a measure of quality of energy and it can be consumed or destroyed through the operation of any physical or mechanical system.			[19]
W_0	Unrecoverable waste: Mass of unrecoverable waste through a product's material going into landfill, waste to energy and any other type of process where the materials are no longer recoverable Where $\mathbf{C_R}$ represents the fraction of the mass of the product being collected for recycling at the end of its use phase and $\mathbf{C_U}$ the fraction of the mass of the product going into component reuse.	$W\mathbf{0} = M(1 - C_R - C_U)$		[18]

3 EXISTING INDICATORS

The literature survey carried out under Task 1.4 revealed a high number of indicators used by various organizations to assess sustainability performance of industrial production. A summary of the existing indicators is provided in this Chapter.

3.1 Sustainable Development Indicators (SDIs)

The European Commission (EC) uses a range of indicator to support policy-making and evaluation at various stages including problem recognition, policy formulation, decision making and monitoring implementation [20]. New indicators are developed and existing indicators are updated whenever necessary in order to supply meaningful information on key environmental, economic and social issues during the policy-making process. One important driver for utilization of sustainability indicators is the Sustainable Development Strategy (SDS), which requires the Commission to develop indicators at the appropriate level of detail to monitor outcomes of the sustainability efforts.

Sustainable Development Indicators (SDIs) are developed by Eurostat within a “hierarchical theme framework” reflecting the seven key challenges of the European SDS as well as the key objective of economic prosperity, and guiding principles related to good governance. The thematic framework covers ten themes including

- socioeconomic development,
- sustainable consumption and production,
- social inclusion,
- demographic changes,
- public health,
- climate change and energy,
- sustainable transport,
- natural resources,
- global partnership,
- good governance [21].

Indicators are further divided into sub-themes to reflect the operational objectives and actions of the SDS [20]. List of SDIs can be found in Table S. 2.

The indicators are also built as a three-level pyramid (Figure 4), providing information on overall and operation objectives in addition to actions. Another group of indicators, termed contextual indicators, complement the indicators at these three levels and basically provide background information [20] [21].The first level of indicators monitors the overall objectives of the SDS with high robustness and data availability. These so-called headline indicators have the highest communication value. Second level indicators correspond to the sub-themes of the framework such as end-use energy efficiency and savings or integration of adaptation to and mitigation of climate change into policies. Third level of indicators is associated with the field of sustainable consumption and production (SCP) [22]. Eurostat indicators at this level are reported to be inadequate to monitor the EU’s progress although. A significant gap in FP funded research regarding these indicators exists. In particular, the need for absolute resource use and not just resource efficiency is underlined [20].

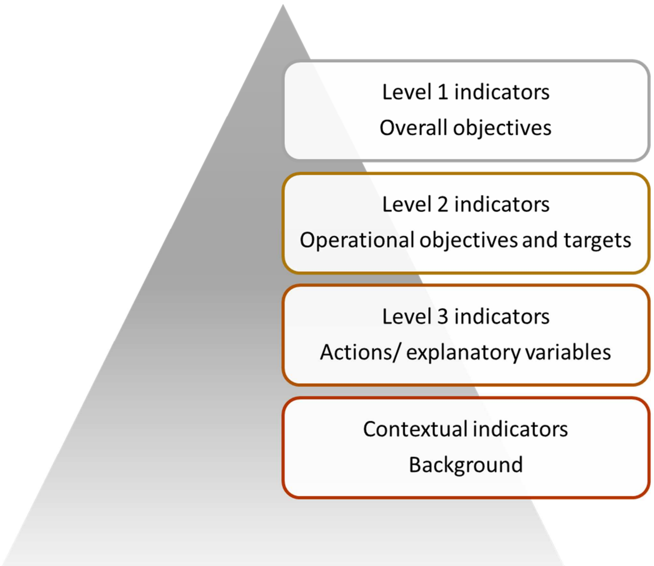

Figure 4 Indicator pyramid of the EU SDI framework [21] [22]

Some other criticism of FP funded research in relation to trends and gaps in use of SDI include:

- Limiting SDIs to economic and environmental aspects with underrepresentation of the social issues.
- Need further attention to indicators for end-use energy efficiency and savings; monitoring the influence of sustainability criteria for biofuels; and the integration of adaptation to and mitigation of climate change into policies.
- Requirement for elaboration of SCP related indicators including the ones reporting absolute/gross values.

3.2 Structural Indicators (SIs)

In addition to the SDIs developed by Eurostat, the EC also selects Structural Indicators (SIs) in order to measure the progress in solution of structural problems over time as requested by the European Council. SIs are a horizontal indicator set, which are used to monitor the Lisbon Strategy for Growth and Jobs The selection process also supports the continuous improvement of the indicators in terms of reliability and quality. The selection process is kept flexible in order create room for inclusion of new priorities and improved indicators to the SI list. However, sufficient degree of stability was also observed for consistency purposes. Additionally, the list of indicators was kept short so as to send clear, simple, and focused policy messages. Still, indicators need to reflect progress in the domains of (1) employment, (2) innovation and research, (3) economic reform, (4) social cohesion, (5) the environment, and (6)general economic background, which necessitate a balanced approach during selection of the indicator list [20] [10] [11].

In order to work on common indicators in particular on social protection and social inclusion process, an Indicators' Sub-Group (ISG) of the Social Protection Committee (SPC) was set up in 2001 under the EC. Main tasks of ISG is to:

- develop and define EU social indicators to monitor member countries' progress towards the commonly agreed objectives underpinning the Open Method of Coordination for social protection and inclusion,
- carry out analytical work based on agreed indicators and develop analytical frameworks to support policy reviews conducted by the SPC,
- contribute to the improvement of social statistics at EU level, particularly through development of the EU Survey on Income and Living Conditions [23] .

The set of common indicators adopted by the SPC in 2006 included 14 overarching indicators in addition to 11 context indicators on social cohesion and interaction with the Lisbon Strategy growth and jobs objectives. There also are 3 strand portfolios of indicators for social inclusion, pensions and long-term care [20].

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

3.3 Indicators Used for the Environmental Policy Review (EPR)

The Annual Environmental Policy Review (EPR) is a report designed to monitor recent environmental trends and policy development at EU and national level and progress towards the EU's key environmental goals [24]. In 2009 report, a total of 37 indicators that reflect different component under DPSIR Framework (Table S. 3). These indicators are categorised under six environmental themes that are (1) climate change and energy, (2) nature and biodiversity, (3) environment and health, (4) natural resources and waste, (5) environment and economy, and (6) implementation [13].

3.4 European Environment Agency (EEA) Core Indicator Set

The core indicator set developed by European Environment Agency (EEA) is based on the DPSIR assessment framework. This set of indicators aims to improve the quality and coverage of data flows so that comparability and certainty of information and the assessments carried out with this information is enhanced. Furthermore, with the core indicator set, contributions to other indicator initiatives in Europe are streamlined. EEA also targets to provide a manageable and stable basis for indicator based assessments to monitor the progress in priority environmental policy areas [25][26]. The indicator within the core set are classified as

- Descriptive indicators,
- Performance indicators,
- Eco-efficiency indicators,
- Policy effectiveness indicators, and
- Total welfare indicators.

3.5 Indicator Studies under Framework Programmes (FP)

These exist a number of EU FP funded research projects focusing on SDIs or developing sustainable development related indicator (Table S. 1). A short summary of notable projects including, INDI-LINK under FP6 and POINT, OPEN-EU and INSTREAM, under FP7 can be found in the following discussion.

The INDI-LINK Project aims to improve the EU SDIs. Existing indicators under Social Inclusion; Sustainable Consumption and Production (SCP); Public Health; Sustainable Transport; and Good Governance were reviewed. Furthermore, evaluation methods for assess the interlinkages between different priorities of the EU SDS were covered. Consequently, some appraisal and evaluation methods including Strategic Environmental Assessment and cost-benefit analysis were identified suitable.

POINT Project aims to help find better ways of using indicators in all aspects of policy, by enhancing the understanding of the factors that condition the successful use and influence of indicators in policymaking. Attention was given to the conceptual validity and reliability of indicators. The IN-STREAM Project focused on the synergies and trade-offs in economic growth and environmental sustainability while performing quantitative and qualitative assessments to establish connections between mainstream economic indicators with key well-being and sustainability indicators. Target of the OPEN-EU Project was to develop a "footprint family" of sustainability indicators which to be placed in a scenario modelling tool for evidence-based policy. Ultimate aim is to contribute to the shift to One Planet Economy by 2050.

ECODRIVE Project seeks to identify best measurement methods for eco-innovation through indicators, which should give indication of progress in terms of economic status, cost reduction, enhanced functionality, and environmental performance (through reduced emissions and resource depletion among other environmental improvements).

On the other hand, the WETO-H2 Project on hydrogen-generated energy used a world energy sector simulation model. During their assessments, indicators including CO2 emissions; share of renewables in electricity; GHG emissions for industry; GHG emissions from industry; GHG emissions from electricity generation; GHG emissions from households and services; GHG emissions from agriculture; and GHG emission for transport were utilized.

3.6 UNEP Sustainable Consumption and Production (SCP) Indicators

UNEP's Sustainable Consumption and Production indicators (SCP) serves the purpose of monitoring the interface between the economy environment and society, and the resource use and waste flows resulting from consumption and production activities. These indicators provide information on whether and at what rate progress is being made towards SCP patterns. They are organized into six domains including (1) scale of resource use, (2) decoupling, (3) environmental impact, (4) technology and lifestyles, (5) financing and investing for SCP, and (6) policy support for SCP [27].

SCP indicators shed light on following issues under the broader topic of sustainable consumption and production:

1. **Resource and critical thresholds/carrying capacity:** Some SCP indicators measure the levels and trends associated with stresses on critical ecosystems and processes occurring within, which may contribute to exceedance of critical thresholds and carrying capacity. Determination of critical threshold and carrying capacities can be extremely difficult, however, the information provided by SCP indicators on this matter provides early warning for decision-makers and public which impacts the policy making process.
2. **Decoupling:** One important aspect of the sustainable consumption and production is the need to decouple economic growth from resource use and environmental degradation. Decoupling, put forward as a policy goal, can involve disconnection of economic growth from resource use or environmental impacts. Resource decoupling refers to the relationship between economic activities with the level of primary resource use. On the other hand, impact decoupling, measured by state or impact indicators, relates to the relationship between economic activities and their environmental impacts.
3. **Social benefits:** Indicators under this theme try to quantify how SCP contributes to better access of society to higher quality and sustainable goods and services while reducing the environmental footprint of consumption, thus social benefits of SCP activities.
4. **Universality:** sustainability is consumption and production is applicable to all countries globally regardless of their level of development. In developed countries, it implies shifting towards more resource- and energy-efficient/circular economies with less waste and emissions, adopting sustainable lifestyles and reducing unnecessary consumption. In developing countries, the concept recognizes the opportunities for establishing sustainability through more resource efficiency, environmentally sound and competitive practices and technologies. Nevertheless, the development status of different countries may dictate different priorities during assessments utilizing SCP indicators.
5. **Linkages to other targets:** SCP, which is a cross-cutting issues, can be addressed directly or indirectly (by focusing on energy, water etc.). Therefore, as indicators are selected for some targets, the information can be used to monitor additional targets as well.

SCP indicators respond to environmental and social concerns taking both supply and demand side of the market and brings a holistic view to assess sustainability. On the production side, SCP refers to the set of cleaner production practices and eco-efficiency of production systems. On the consumption side, it refers to the shift in consumer behaviour towards more sustainable practices in order to reduce environmental footprints.

3.7 European Benchmark Indicators (EBI)

The European Benchmark Indicators (EBI) are developed by The Netherlands Environmental Assessment Agency (MNP) to support comparison to be made between Member State's environmental performances. Apart from reflecting the environmental performance, they also consider economic and social setting of a country based on the fact that environmental can be very different because of differences in e.g. demography and economic structure [28].

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

The EBI have been divided into two parts; first on socioeconomic profile, that should put environmental performance into proper perspective and second on the environmental profile built upon the OECD's DPSIR framework. Whenever possible, socioeconomic indicators covers data on the present situation and trends from the past. The environmental indicators are measures on the basis of environmental pressures and include existing aggregated indicators such as Ecological Footprint [28]. Composite indicators help to assess the overall ranking of the country among other Member States.

3.8 Beyond GDP indicators

The Gross Domestic Product (GDP) is the sum of the market value of all final goods and services produced in a country in a given period. GDP per capita has traditionally been used to illustrate a country's material standard of living, but today its usage is meeting rising criticism [29]. The use of Gross Domestic Product (GDP) to measure key societal goals such s well being and sustainability is under discussion, which focuses around the limitation of GDP to measure societal progress beyond economical and financial indicators. The cons against use of GDP in such indicators for normalization purposes include the difficulty to relate economic issues such as calculating depreciation, particularly for the natural assets. Furthermore, some specific non-market phenomena (e.g. household-produced services for own consumption) are not taken into account [30].

To complement GDP — the monetary measure of economic production — with environmental information, the EC has worked on an EU index on environmental pressures that express the impacts of human activity on the natural environment [30]. The aim of this index is to assess the results of *domestic* environmental protection efforts. A fall in the value of the index would show that progress is being made on domestic environmental protection. In addition, comparing this index with the one on global environmental impacts can show the extent to which the EU is 'exporting' environmental pressures [30].

The global perspective on of the EC to develop an index beyond GDP involves the "environmental footprint" approach, which basically utilized a set of life cycle based environmental impact indicators. The key purpose was to measure the worldwide environmental impacts along the supply chain relating to European consumption, and the eco-efficiency of resource use. Under this scope, 11 dimensions of environmental impacts were included in a single index:

1. climate change,
2. ozone depletion,
3. human toxicity,
4. respiratory inorganics / particulate matter,
5. ionising radiation,
6. photochemical ozone formation,
7. acidification,
8. eutrophication,
9. ecotoxicity,
10. land use,
11. resource depletion.

Comparing the overall index figure or the individual indicators for the 11 dimensions with GDP provides the aggregate and 11 specific 'eco-efficiency' indicators. They can help tracking progress towards a green and resource efficient economy (see Figures 1 and 2 in Annex 2) [30].

3.9 Overview of existing Resource efficiency methodologies and tools

Several tools for measuring sustainability have been developed, nevertheless, the definition of a suitable environmental and/or sustainability metric for supporting objective environmental and/or sustainability assessments is an open issue within the literature [31]. Many different concepts and methods have already been developed for the environmental, economic, and/or social evaluations of particular processes, products or activities [32], e.g., LCA, Life Cycle Cost (LCC), the ecological footprint (EF), the environmental sustainability index, the measurement of net savings, and others. Previous reviews of indicators for measuring sustainability have included studies by Hák et al. (2007), Ness et al. (2007), Singh et al. (2009), Herva et al. (2011), Roca and Searcy (2012), etc. [33][34][35][36][37].

The following sections provide an overview of various sustainability indices focusing on sustainable resource management and resource optimization problems, with the information related to formulation strategy, scaling, normalization, weighting and aggregation methodology.

3.10 Ecosystem-Based Indices for Industries

This sub-section aims to review the ecosystem assessment methods developed in the last years that are suitable to be applied under a process and product oriented approach.

Table 6 Ecosystem-Based Indices for Industries

Name	Nr. of sub-indicators	Scaling/normalisation	Weighting	Aggregation
Material Input Per unit of Service (MIPS)	Five categories	MI factors	Equal	-
Sustainability Performance Index	5	Area	Equal	Total area per unit product divided by area per capita
Ecological Footprint	6	Area	Equal	Summation
Sustainable Environmental Performance Indicator	5	Area (deviation-from-target methodology)	Equal	Radar diagram
Eco-compass	6	Indices are expressed in monetary terms	Different weighting vectors lead to different optimal life loci	–
Environment assessment for cleaner production	5 "profiles"	Mathematical formula for each indicator	Equal	Square root of the sum of squares of profile indices
COMPLIMENT	Five categories	Life Cycle Impact Assessment	AHP	Weighted sum

Material Input Per unit of Service (MIPS)

MIPS stands for Material Input Per Service unit, a measure developed at the Wuppertal Institute. MIPS, as a targeted and practicable indicator, helps to show up the positive as well the financial potential of a resource-conserving entrepreneurship (use and service management, cost and resource efficiency). MIPS calculates the use of resources from the point of their extraction from nature: all data corresponds to the amount of moved tons in nature, thus to the categories of biotic or renewable raw material, abiotic or non renewable raw material, water, air and earth movement in agriculture and silviculture (incl. erosion).

Sustainability Performance Index (SPI)

The Sustainability Performance Index (SPI) is based on an operationalised form of the principle of sustainability. It uses only process data known at an early stage of planning and data of natural concentrations of substances (not on their presumable impact, which is usually not known). The core of the SPI evaluation is the calculation of the area needed to embed a process completely into the biosphere [38]. This comprises the area required for production of raw material, process energy and provided installations as well as the area required for the staff and for the accumulation of products and by-products within the available area [39].

Project funded by the European Union's
Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

Ecological Footprint (EF)

The ecological footprint (EF) is based on the quantitative land and water requirements to sustain a (national) living standard into infinity thereby assuming certain efficiency improvements [40]. The ratio of required resources to available resources is interpreted as a measure of ecological sustainability: ratios exceeding one are seen as unsustainable, i.e. contemporary living standards would violate the principles of sustainable development. Calculation of the EF is based on data from national consumption statistics. Thus, the EF primarily relies on normalisation (as any consumption is converted in land use). Weighting is rather implicit in the conversion parameter and aggregation is done by adding up all land and water requirements. There are several approaches similar to the EF, e.g. the MIPS (Material-Input-Per-Service) concept or the Ecoindex™ [41] [42] [43].

Sustainable Environmental Performance Indicator (SEPI)

The Sustainable Environmental Performance Indicator (SEPI) was only recently suggested, and it is designed to be composed of any combination of quantitative indicators, although it is currently depicted as a combination of different footprints. The SEPI indicator and an approach that complements environmental, financial and other considerations were described in detail by De Benedetto and Klemeš (2009a&b) [44][45] .

The limited inclusion of cost and investment considerations significantly restricts the applicability of LCA as a source of input for strategic decision-making. Accordingly, the Environmental Performance Strategy Map (EPSM) was developed. The EPSM integrates financial, environmental, resource, and toxicological considerations into a single analysis. Environmental and social footprints are considered. Moreover, cost is considered as an additional category that relates to all of the other categories. The objective of the EPSM is to provide a single indicator for each option. The best option from the environmental or social and financial perspectives can subsequently be selected based on this approach. A deviation-from-target methodology is used, in which a maximum target is defined for each of the footprints, and each value is expressed as a percentage of the distance to that target. The normalised values of the footprints are mapped on a spider diagram. The cost is considered as an additional dimension because it is not used for comparative reasons. The volume of each pyramid represents the overall environmental or social and financial impact of the option under consideration. This indicator is termed the SEPI. The EPSM enables the comparison of different footprints based on a single SEPI.

The advantage of using EPSM is that it combines the main indicators with the SEPI as a single measurement for the sustainability of a given option. However, the weaknesses are also, amongst others, the limited availability and uncertainty of data, time intensiveness to perform the study, and highly possible errors relating to the conversion of emissions to an area unit.

Eco-compass

The Eco-compass has been developed by Dow Chemical to provide a simple, visual summary of LCA data [46]. It is based on the indicators of eco-efficiency developed by the World Business Council for Sustainable Development (WBCSD), with some minor amendments [47]. The Eco-compass has six 'poles' or dimensions:

- energy intensity
- mass intensity
- health and environmental potential risk
- resource conservation
- extent of re-valorization (re-use, re-manufacturing and re-cycling)
- service extension.

Environment Assessment for Cleaner Production Technologies

Fijal (2007) developed an environmental assessment method for cleaner production technologies enabling quantitative analysis of environmental impact [48]. The method is based on material and energy flows and uses a set of profile indices, including raw material, energy, waste, product and packaging profiles that describe all material and energy flows related to the technology under investigation. The indices are used as a basis for determining an

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

integrated index for overall environmental assessment of cleaner production technologies. The presented method can be employed to evaluate environmental nuisance of implemented, modernised and modified technological processes and products as well to perform comparative analyses of alternative technologies.

COMPLIMENT—Environment Performance Index for Industries

Hermann et al. (2007) developed an analytical tool, called COMPLIMENT, which can be used to provide detailed information on the overall environmental impact of a business [49]. COMPLIMENT integrates parts of tools such as life cycle assessment, multi-criteria analysis and environmental performance indicators. The methodology is based on environmental performance indicators, expanding the scope of data collection towards a life cycle approach and including a weighting and aggregation step. The method starts with the selection of EPIs to be calculated while taking into account the goal and scope definition of an LCA, followed by data collection, analysis and conversion and subsequently the classification, characterisation and normalisation steps. Carrying out classification, characterisation and normalisation result in a set of output data in the form of impact categories, such as global warming, acidification potential, eutrophication potential, ozone precursors and human health. Three sets of weights based on local, regional and national perspectives were developed using AHP analysis. As a next step in applying COMPLIMENT, the weights per impact category) are multiplied by the normalised potential impacts per category. The resulting weighted impacts per category can then be added up to form an index of the normalised total potential environmental impact for each perspective.

3.11 Composite indices for industries

Composite indicators are an innovative approach to evaluating sustainable development and resource efficiency. There were numerous attempts in literature to move beyond the non-integrated and combine different nature-society dimensions in a single evaluation methodology. Firstly the three aspects of sustainable development were faced through the development of methodological framework, with relatively simple, informative and easily available indicators .

Nevertheless, aggregation was not considered in the above-mentioned methodologies. Computing aggregate values is a common method used for constructing indices. An index can be either simple or weighted depending on its purpose. Such an approach allows for the evaluation of a multitude of aspects, which can then be deciphered into a single comparable index.

The construction of composite indicators involves making choices, with issues of uncertainty such as selection of data, imprecision of data, data imputation methods, data normalisation, weighting schemes, weights values and aggregation methods. This sub-sections aims to review the most relevant methodologies within this field.

Table 7 Composite Indices for Industries

Name	Nr. of sub-indicators	Scaling/normalisation	Weighting	Aggregation
Composite Sustainable Development index	Three categories; 38 indicators	Distance from maximum and minimum	AHP	Weighted average
Composite Sustainability Performance Index	Five categories; 59 indicators	Distance from mean divided by standard deviation	AHP	Weighted average
ITT Flygt sustainability index	40	[+10, −100]	Company opinion	Summation
G score	5 categories	Subjective	Equal	Summation
Methodological approach of Politecnico di Milano	NA	NA	NA	NA

Project funded by the European Union's
Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

Composite Sustainable Development index

Krajnc and Glavic (2005) collected and developed a standardized set of sustainability indicators for companies covering all main aspects of sustainable development [50]. A composite sustainable development index (ICSD) in order to track integrated information on economic, environmental, and social performance of the company with time. Normalised indicators were associated into three sustainability sub-indices and finally composed into an overall indicator of a company performance. This was applied by determining the impact of individual indicator to the overall sustainability of a company using the concept of analytic hierarchy process.

Composite Sustainability Performance Index (CSPI)

The composite sustainability performance index (CSPI) is an attempt to develop a measure of corporate citizenship and to critically evaluate how well a company stands up to its policies and commitments regarding sustainable development. This model enables industry to identify the key sustainability performance indicators and provides framework for aggregating the various indicators into the CSPI [51]. The calculation of CSPI is a step-by-step procedure of grouping various basic indicators into the sustainability sub-index for each group of sustainability indicators. Sub-indices then subsequently derived in the form of aggregated index. Weights are derived using AHP methodology. Liberator scoring and Z score method were employed for aggregation of indicators. The model has been evaluated based on the real-time application for a steel industry. CSPI with its sub-indices for each dimensions of sustainability were evaluated for the time period of 4 years.

ITT Flygt Sustainability Index

ITT Flygt Sustainability Index suggests a method for measurement of corporate contribution to sustainable development, looking at how well a company stands up to its policies and commitments regarding sustainable development. This index is developed and calculated for ITT Flygt AB over a 3 years period (2002–2004). The index structure is based on scientific literature and interviews with ITT Flygt and four other engineering companies. The purpose of the index is to support corporate sustainability-management. The index is calculated by aggregating some 40 sustainability-indicators. These indicators are individual to each company and are designed to measure the significant sustainability aspects of the company [52].

G Score method

“G score” consists of five categories, namely general environmental management (GEM), input, process, output, and outcome. G score is a proxy measure of corporate environmental performance based on voluntary environment, health, and safety (EHS) report and is calculated by aggregating the points of the above five-categories [52].

Development of a methodological approach and application to the iron and steel sector. The document “Come Misurare la Sostenibilità: Sviluppo di un Approccio Metodologico e Applicazione al Settore Siderurgico” by M. G. Maruccia and M. Pinzone is very interesting because it provides a General Methodology and then applies it to a specific industrial sector. This methodology, on the basis of ‘Sustainability Reporting Guidelines of GRI - The Global Reporting Initiative, proposes a general methodological approach for the identification of a set of significant process, energy, environmental and social indicators useful to characterize an industrial process, and then applies the methodological approach to the specific industrial sector of iron and steel plants, thus providing a reference for the application of a methodology to a specific industrial sector in an effective way [54].

Project funded by the European Union’s
Horizon 2020 research and innovation programme under
grant agreement № 642154.

4 INDICATOR SELECTION AND ASSESSMENT METHODOLOGY IN FISSAC PROJECT

4.1 Structure of the indicator set proposed for the FISSAC Project

Within the scope of FISSAC Project (i) Environmental, (ii) Economic, (iii) Social as well as (iv) Circularity and Network indicators are covered. The initial list of indicators obtained as a result of the literature review was first evaluated based on the type of information required for quantification. Following types of indicators were covered in the literature review:

- Sectorial KPIs
- Resource efficiency indicators
- Sustainable consumption and production indicators
- ETV indicators
- IS indicators
- Circularity indicators
- Network strength analysis indicators.

In order to provide a structure to the indicator set, data feeding the indicators were grouped as inflows to the system (raw materials, energy, water, operational and capital costs etc.) or outflows from the system (products, turnover, emissions, waste etc.). Data needed for social (except man-power) as well as circularity and network indicators were excluded from this grouping. The “Domains and Themes” of indicators respectively constitute to the first two rows of the indicator matrix prepared as an output of Task 1.4 (Table 8).

On the columns of this matrix, the “Classes and Subclasses of Indicators” proposed for the FISSAC Project was categorised as:

1. “Baseline Performance Indicators”, which quantify the performance of the FISSAC network in a static manner in terms of
    - 1.1. ***Absolute Quantity Indicators***: These reflect total quantities of entities that are being monitored through indicators in a company or overall network. The need for absolute quantity indicators are underlined in the literature and also included as a criteria for selection of indicators. Examples of absolute quantity indicators include total raw material consumed by a factors or total turnover of the company over a year.
    - 1.2. ***Intensity Indicators***: These are also called ***specific indicators***, which are obtained through normalization of absolute quantity indicators. The normalization for baseline indicators can be carried out based on (i) product quantity, (ii) turnover or (iii) net value added. Examples for intensity indicators include specific energy consumed or quantity of waste generated per unit amount of product. Specific indicators help to understand the trends in production processes on a common basis. Not only they are useful as stand-alone indicators but they also facilitate comparisons between companies.
2. “Impact Indicators”, which quantify the change in performance over time in terms
    - 2.1. ***Change in Absolute Quantities***: These quantify the extend of change in absolute quantities between two set period of times; for instance change in annual decrease or increase in overall raw material consumption of a factory. By comparing change in absolute quantities, it is possible to obtain the ratio of increase or decrease.
    - 2.2. ***Change in Intensity (Efficiency Indicators):*** This group of indicators show the change in specific indicators. Since they use specific indicators for calculation, they are normalised over product quantity, turnover or net value added. They present the ability to monitor substitution or recycling rates or relative change intensity with respect to a baseline. Baseline of comparison can be any benchmark case selected by the user. One such benchmark can be the situation before establishment of the IS network. Also it is possible to obtain the trend in performance of indicators over years and carry out forecast analysis depending on the statistical fitness of the data.

Overall indicator structure used in this report is summarized in Figure 5.

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

Table 8 Structure of FISSAC indicator set (sample)

		INDICATOR CLASSES										
		Baseline Performance Indicators				Impact Indicators						
	INDICATOR THEMES	Total	Specific (Intensity)			Change in Total				Change in Specific (Efficiency)		
Domain	Inputs (Resources)	Amount	/Product Quantity	/Turnover	/Net Value Added	Increase or Decrease	Rate of Incr. or Dec.	Subst. or Recycled	Rate of Subs or Rec.	/Product Quantity	/Turnover	/Net Value Added
ENV	Material Use	ton	ton material/ ton product	ton material/€	ton material/€	ton	% of baseline	ton	% of baseline	% of baseline	% of baseline	% of baseline
ENV	Energy (and Exergy) Consumption	kWh	kWh energy/ ton product	kWh energy/€	kWh energy/€	kWh	% of baseline	kWh	% of baseline	% of baseline	% of baseline	% of baseline
ENV	Water Consumption	m3	m3 water/ ton product	m3 water/€	m3 water/€	m3	% of baseline	m3	% of baseline	% of baseline	% of baseline	% of baseline
ECO	Operational Cost (OPEX)	€	€/ton product	€/€	€/€	€	% of baseline	-	-	% of baseline	% of baseline	% of baseline
ECO	Capital Cost (CAPEX)	-	-	-	-	€	-	-	-	-	-	-
ENV	Land Use	m2	m2/ ton product	m2/€	m3 water/€	m2	% of baseline	-	-	% of baseline	% of baseline	% of baseline
SOC	Man-power	man-month	m3 water/ ton product	m3 water/€	m3 water/€	man-month	% of baseline	-	-	% of baseline	% of baseline	% of baseline
	Outputs (Value)											
ECO	Product Quantity	ton	-	-	-	ton	% of baseline	-	-	-	-	-
ECO	Turnover	€	-	-	-	€	% of baseline	-	-	-	-	-
ECO	Net Value Added	€	-	-	-	€	% of baseline	-	-	-	-	-
	Outputs (Wastes)											
ENV	Air Emissions	ton	ton emission/ ton product	ton emission/€	ton emissionl/€	ton	% of baseline	ton	% of baseline	% of baseline	% of baseline	% of baseline
ENV	Wastewater	m3	m3 wastewater/ ton product	m3 wastewater/€	m3 wastewater/€	m3	% of baseline	m3	% of baseline	% of baseline	% of baseline	% of baseline
ENV	Solid Wastes (disposed before IS)	ton	ton waste/ ton product	ton waste/€	ton waste/€	ton	% of baseline	ton	% of baseline	% of baseline	% of baseline	% of baseline
ENV	By-Products (valorized before IS)	ton	ton by-product/ ton product	ton by-product/€	ton by-product/€	ton	% of baseline	ton	% of baseline	% of baseline	% of baseline	% of baseline
ENV	Waste Heat	kWh	kWh heat/ ton product	kWh heat/ €	kWh heat/ €	kWh	% of baseline	kWh	% of baseline	% of baseline	% of baseline	% of baseline

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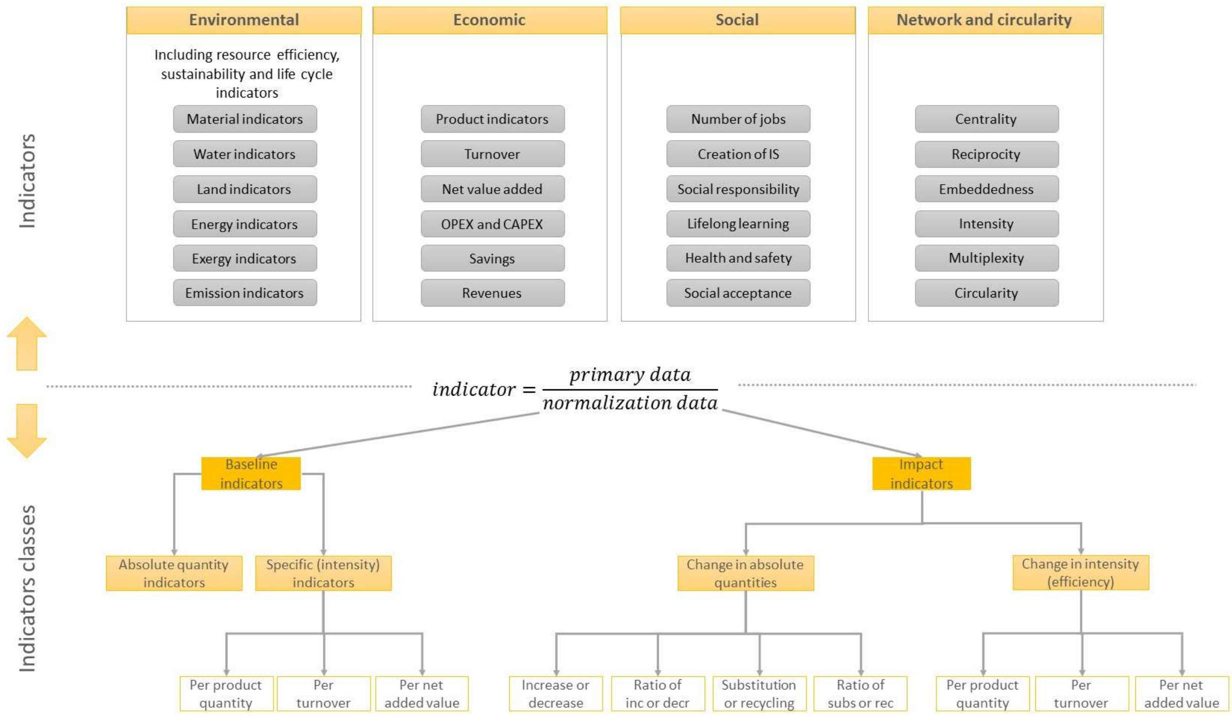

Figure 5 Indicators structure for FISSAC IS indicator set

4.2 Indicator-based assessment

Indicator based assessment in FISSAC:

1. Define a desired evolution for each indicator, on the basis of the frame of reference.
2. Determine a method to compare the desired evolution with the observed evolution or status of the indicator, and define the thresholds to delimit what observed evolution is considered fully, partially and not corresponding to the desired evolution (resulting in a positive, neutral and negative qualification of the indicator).
3. Calculate the observed evolution or status of the indicator in the period analysed.
4. Compare the observed evolution of the indicator with the desired evolution using the method determined in step 2. Depending on the result of the comparison (observed evolution fully, partially or not corresponding to the desired evolution) and according to predefined thresholds, the indicator is attributed to a positive, negative or neutral class (or any intermediate class between "positive" and "negative").

In this process, it is important to distinguish between the desired (or observed) direction (increase, decrease or stability) and the result of the indicator-based assessment (positive, neutral or negative qualification of an indicator) [6].

During selection of indicators in the next Chapter under Task 1.4, following criteria is observed:

- Coverage of all relevant categories and resources and completeness of scope
- Coherence in terms of indicator structure, detail
- Ability to reveal trade-offs and cross-media effects or burden shifting
- Inclusion of absolute indicators in addition to specific indicators
- Potential for meaningful interpretation of results in terms of decoupling
- Ease of estimation with data available to industrial companies, i.e. utilization of mass and energy balances during calculation
- Ease of estimation with reliance on expertise available to industrial companies
- Representative picture of material flows and their interactions with the environment

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- Simplicity, ease of interpretation and ability to show trends over time
- Responsiveness to changes in economic activities, resource productivity, technology development and environment
- Ability to make comparisons with a threshold or a reference value

4.3 Quality Assurance and limitations

From the quality assurance stand point during implementation of indicator based assessment, the user should always keep the following in mind: indicators only give an insight on changes happening; they dot explain [7]. They are considered as practical proxies for change. Therefore, the system should be further analysed substantively to understand why the change has happened. Only than meaningful or sound strategies and policies can be put into action.

For the indicator based assessment to provide the maximum level of benefit, the indicators should be in compliance with SMART and RACER criteria. The quality of the assessment results are also dependent on the quality of data used for quantification of indicators. In other words, data quality is the key for a credible indicator based assessment [7].

5 EVALUATION OF INDICATORS

5.1 Definition of terms

By-products: In an industrial process, major aim is to manufacture the primary (principal) product. However some other materials, which have low value in comparison with the primary product, may be generated. Those materials are termed as by products. They are either sold in their original state with a significantly lower economic value when compared to primary product or they simple exchanged free of charge. By-products are very good candidates for up-cycyling operations due to their relatively low economical value.

Greenhouse gas emissions (GHG): The six main greenhouse gas emissions are:
• Carbon dioxide (CO2);
• Methane (CH4);
• Nitrous oxide (N2O);
• Hydrofluorocarbons (HFCs- a group of several compounds);
• Perfluorocarbons (PFCs- a group of several compounds); and
• Sulphur hexafluoride (SF6) [15].

Net Value Added: Net value added has different meanings in different fields like economics, statistics or development studies. In business economics, net value added is obtained by deducting consumption of fixed capital (or depreciation charges) from gross value added which is the (revenue – cost of goods and services purchased) [55]. The resulting figure is defined as follows:

$$\text{Net value added} = \text{Revenue} - \text{Cost of goods and services purchased} - \text{Depreciation on tangible assets}$$

In environmental studies, it is used as a normalization figure especially with multi-product companies, where for example tonnes of production is not meaningful. As it is the case for “turnover” it is usually expressed in monetary terms.

Non-product output: Within the scope of the report, non-product output is defined as all the materials that are not upcycled or valorized within the industrial network. Therefore, by definition down-cycled waste is also covered under the category of non-product output.

Primary (virgin) raw materials: Primary raw materials are the product of the primary production sectors, which encompass the extraction of natural resources from the environment and their transformation through processing or refining. The obtained raw materials are primary commodities, the base materials for further manufacturing and consumption processes. These materials will finally end up as waste, from which secondary raw materials can be derived [56].

Raw materials: Raw materials are basic substances or mixtures of substances in an untreated state except for extraction and primary processing. They can be subdivided into primary and secondary raw materials [56].

Receiving processes: Industrial processes in a symbiosis network, which utilize waste/by-products as secondary raw materials.

Secondary raw materials: Waste materials that have been identified for their potential for recycling or reprocessing to generate raw materials (potentially displacing the use of primary materials), for example: mining wastes, manufacturing and processing waste, including scrap, and contents of landfill [57].

Supplying processes: Industrial processes in a symbiosis network, which provide waste/by-products to receiving processes to be utilized as secondary raw materials.

Turnover (Revenue): Turnover represents the sales made by a company of its products/services in a period, which can be a month, quarter, half-year or full year. Turnover is usually expressed in monetary terms. The term is often just referred to as sales or net sales, which means revenues without VAT. It is different from “profit” which is the residual earnings of a business after all expenses have been charged against net sales.

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Waste: Any substance or object which the holder discards or intends or is required to discard. The Waste Framework Directive 2008/98/EC (see WFD) provides detail on the full scope of waste in relation to parallel Directives on the treatment of specific products and materials and the way it should be classified and reported at EU level [58]. The major difference between wastes and by-products lie behind their existing use, economic value and treatment (or disposal) needs. In most cases, solid wastes have very limited industrial use, very low (even negative) economic value and subject to treatment or final disposal.

5.2 Indicator classes

Classes, which are proposed for the FISSAC Project, were divided into two namely “Baseline Performance Indicators” and “Impact Indicators”. These two indicator classes are composed of subclasses of indicators, which are explained below in detail:

5.2.1 Baseline Performance Indicators

Baseline performance indicators aim to provide insight on status of a system (e.g. plant level, sector level, IS network level) in a static manner, i.e. they provide a snapshot of the system over a given time. Although not explicitly mentioned, the indicators always cover a certain period of time. This is a basic requirement of the SMART criteria, which necessitate indicators to be time-bound. In most cases, for manufacturing processes, this is likely to be one year but it could be longer or shorter. The user of the methodology should state the time period used for the calculation [18]. Baseline performance indicators are essential for monitoring of the environmental, economic and social performance of a system. They can either indicate the absolute values of variables (Absolute Quantity Indicators) or specific values of variables (Intensity Indicators).

5.2.1.1 Absolute quantity indicators

The findings for the assessment of available indicators under SCP suggest the need for absolute resource use in addition to resource efficiency [20]. Baseline indicators under this class are estimated from the total amount of raw material, energy or water use on the consumption side or the quantity of products, by-products or waste generated on the production side. Units for these indicators can be mass, energy, volume or monetary depending on the numerator. Also, depending on the type product, common product units such as volume (for instance for liquid products), energy or area (for products such as ceramic tiles) are possible and can be used for normalization purposes.

Calculation: No further calculation is required because it is based on direct data.

Examples: PRM consumption, SRM consumption, Turnover, Net value added (Table 5)

Table 9 Absolute Amount of Inputs or Outputs of Company A[2]

Company A	***Before IS Applications - Baseline (2016)***	***After IS Applications (2017)***
PRM consumption	650 tonne	580 tonne
SRM consumption	0 tonne	70 tonne
Production	550 tonne	550 tonne
Turnover	55 M€	55 M€
Net value added	10 M€	10 M€

[2] This table presents a hypothetical case of SRM substitution in a random Company A. Before IS, this company used to consume 650 tonnes of PRM for manufacturing 550 tonnes of product. The turnover and net value added as well as the production volume is assumed to stay same before and after IS. However, during indicator based assessment in real IS networks, possible change in these should also be monitored.

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5.2.1.2 Intensity of consumption or production

Intensity indicators provide an insight on normalized values by dividing total consumption or production indicators with amount of production, turnover value of the company or net added value created by manufacturing processes or the establishment of the IS network. Intensity indicators, which are also called specific indicators, provide a basis for comparison between different system sharing a common denominator. Units for these indicators always contain the unit of what is being measured and the unit of item used for normalization, i.e. mass/mass, mass/monetary value, energy/mass, volume/monetary value etc. Also, depending on the type product, common product units such as volume (for instance for liquid products), energy or area (for products such as ceramic tiles) are possible and can be used for normalization purposes.

Calculation:

In terms of product amount: $$\frac{Absolute\ quantity}{Amount\ of\ product\ (in\ mass, volume\ or\ area)}$$

In terms of product turnover: $$\frac{Absolute\ quantity}{Amount\ of\ turnover\ (in\ monetary\ unit)}$$

In terms of product net value added: $$\frac{Absolute\ quantity}{Amount\ of\ net\ value\ added\ (in\ mass, volume\ or\ area)}$$

Examples: PRM intensity (i.e. specific PRM consumption/utilization), SRM intensity (i.e. specific SRM consumption/utilization)

Table 10 Intensity Indicators for Company A

Company A	***Before IS Applications - Baseline (2016)***	***After IS Applications (2017)***
PRM intensity	1.18 tonne PRM / tonne Product	1.05 tonne PRM/ tonne Product
SRM intensity	0 tonne SRM/ M€ turnover	1.27 tonne SRM/ M€ turnover

5.2.2 Impact Indicators

The purpose of using the impact indicators is to understand how the performance of the system is changing over time. Different from the baseline indicators, impact indicators are estimated by comparing the status of the system at two different points in time. They are calculated from the total and specific (intensity) baseline indicators calculated at the beginning and end of a time frame.

5.2.2.1 Absolute change in inputs/outputs

These indicators estimate the change, in terms of increase or decrease, in total consumption or production. The difference is the change in gross quantity of resources used or products/wastes generated. Units for these indicators can be mass, energy, volume or monetary depending on the numerator. Also, depending on the type product, common product units such as volume (for instance for liquid products), energy or area (for products such as ceramic tiles) are possible and can be used for normalization purposes.

Calculation: $$\text{Absolute Quantity in Baseline} - \text{Absolute Quantity at a Specific Time}$$

Examples: Absolute change in PRM, absolute change in product quantity

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Table 11 Absolut Change in Inputs/Outputs of Company A

Company A	***Between 2016 and 2017 (Before and After IS Applications)***
Absolute Change in total PRM consumption	70 tonne
Absolute Change in production amount	0 tonne

5.2.2.2 Relative Change in Inputs/Outputs

Ratio of increase and decrease class indicate the change of total consumption and production reported on the basis of a baseline. The indicators estimate the % change in total consumption and production with respect to a baseline.

Calculation:

$$100\ x\ \frac{(\text{Absolute Quantity in Baseline} - \text{Absolute Quantity at a Specific Time})}{\text{Absolute Quantity in Baseline}}$$

Examples: Relative change in total PRM consumption

Table 12 Relative Change in Inputs/Outputs of Company A

Company A	***Between 2016 and 2017 (Before and After IS Applications)***
Relative Change in total PRM consumption	10.7 %

5.2.2.3 Amount of Substitution/Recycling of Inputs/Outputs

One crucial aspect of the IS networks is the valorization of waste and by-products in different production processes. Such upcycling processes generally result in substitution of some primary raw materials. Therefore, it is important to monitor the amount of waste recycled or used as secondary raw material and the amount of primary raw materials substituted. This indicator class reports the total quantities of recycling or substitution. Their units can be mass, energy or volume. Also, depending on the type product, common product units such as volume (for instance for liquid products), energy or area (for products such as ceramic tiles) are possible and can be used for normalization purposes.

Calculation: For substituted flow and valorised flows, this indicator is equal to the absolute change in inputs for that flow.

5.2.2.4 Relative change in substitution/recycling of inputs/outputs

Rate of substitution or recycling provides information the how much of the waste is recycled with respect to total waste generation or how much of the primary raw materials consumed is substituted. Unit for these indicators are %, as they measure the change on the basis of a reference case (baseline).

Calculation: For substituted flow and valorised flows, this indicator is equal to the absolute change in inputs for that flow.

$$100\ x\ \frac{(\text{Absolute Quantity in Baseline} - \text{Absolute Quantity at a Specific Time})}{\text{Absolute Quantity in Baseline}}$$

Examples: PRM substitution, SRM valorisation

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Table 13 Relative Change in substitution and valorisation of Company A

Company A	***Between 2016 and 2017 (Before and After IS Applications)***
PRM substitution	10.7 %
SRM valorisation	10.7 %

5.2.2.5 Change in baseline input/output intensity (efficiency)

Change in Baseline Input/Output Intensity (In addition to observing change in absolute values of mass, energy, volume or money, change in baseline can be monitored as impact indicators. These so-called efficiency indicators compare the intensity indicators (reported per product, turnover or net added value) with a baseline.

Calculation: For substituted flow and valorised flows, this indicator is equal to the absolute change in inputs for that flow.

$$100\ x\ \frac{(\text{Intensity in Baseline} - \text{Intensity at a Specific Time})}{\text{Intensity in Baseline}}$$

Examples: PRM efficiency

Table 14 Efficiency or inputs of Company A

Company A	***Between 2016 and 2017 (Before and After IS Applications)***
PRM substitution	29 %

Figure 6 provides an example for the indicator classes using primary, secondary and total raw material indicators as a sample. Here primary and secondary consumption, which are absolute indicators, are estimated from direct data. In order to convert total consumption values, total PRM and SRM consumption can be divided by product quantity, turnover, or net value added. By comparing intensity indicator for the baseline and IS case, it is possible to estimate the % change in specific PRM and SRM consumption. In order to learn how much change in total PRM and SRM consumption occurs, the difference between total PRM and SRM consumption for baseline and IS cases should be obtained. This provides the user with the indicators for change in absolute quantities. Finally the substation or valorisation ratios can be obtained by dividing the total decrease in PRM consumption after IS with total initial PRM consumption and total increase in SRM consumption after IS with total initial RM consumption to reach PRM substitution and SRM valorisation indicators respectively.

This example also shows that for material consumption indicators it is sufficient to have the knowledge on PRM and SRM consumption figures. Rest of the indicators including total raw material consumption can be calculated by using this basic set of information. Of course for intensity indicators, the normalization data need to be known by the user.

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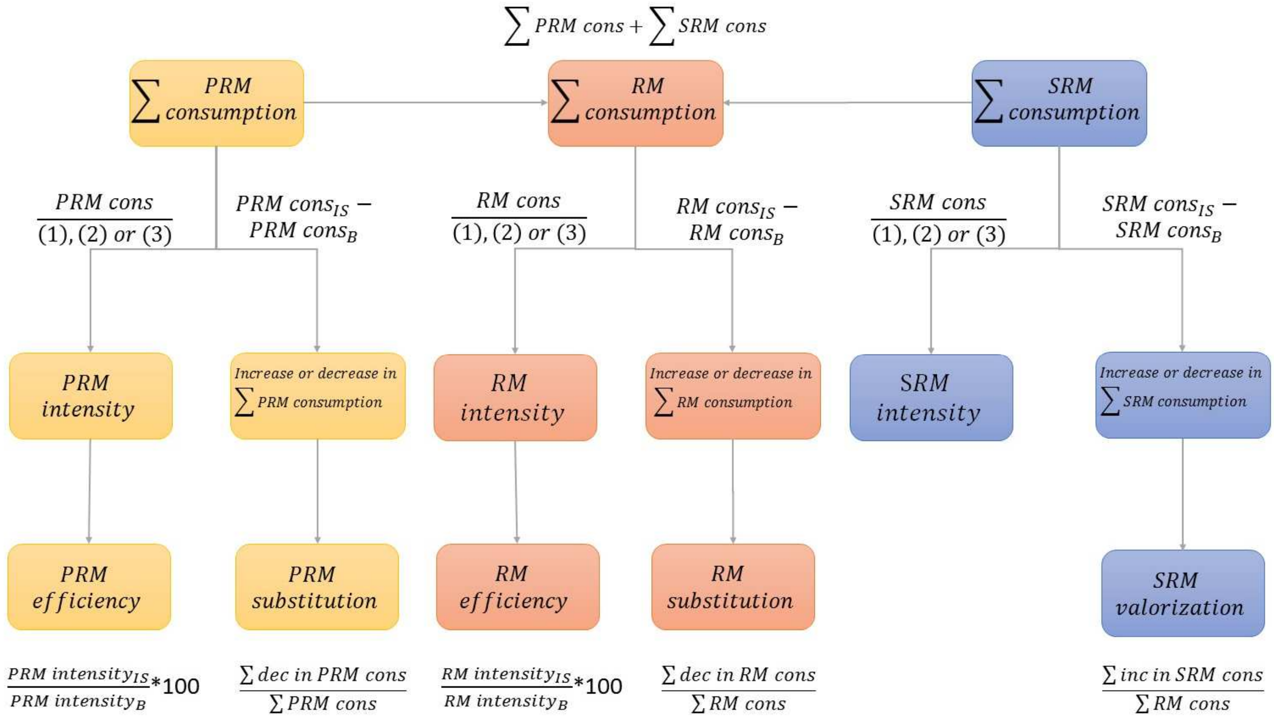

Figure 6 Schematic representation of absolute, absolute change, intensity and efficiency indicators based on primary and secondary material consumption (Note: (1) product quantity, (2) turnover, (3) net value added)

5.3 Proposed Indicators for the FISSAC IS Network

5.3.1 Basic Environmental Indicators

Environmental indicators proposed in this section are based on the DPSIR Framework.

5.3.1.1 Material Consumption

Materials used by weight or volume describes the reporting organization's contribution to the conservation of the global resource base and efforts to reduce the material intensity and increase the efficiency of the economy. These are expressed goals of the OECD Council and various national sustainability strategies. For internal managers and others interested in the financial state of the organization, material consumption relates directly to overall costs of operation. Tracking this consumption internally, either by product or product category, facilitates the monitoring of material efficiency and cost of material flows [15]

To address this growing concern, the European Commission launched the European Raw Materials Initiative in 2008 and adopted in 2011 a strategy document which sets out targeted measures to secure and improve access to raw materials for the EU, based on a three-pillar approach:

- fair and sustainable supply of raw materials from international markets,
- fostering sustainable supply within the EU, boosting resource efficiency and promoting recycling [59].

In industry, resource efficiency is often defined in supply chain terms, highlighting a firm's material, natural resource and energy efficiencies, and the generation and impact of waste. In some cases, only the resource efficiency of non-energy carrying materials is considered. In this case, the term 'material productivity' is used [11].

SRM utilization in total raw material consumption at the receiving end of a symbiotic relationship is addressed by a company's ability to use recycled input materials. Using these materials helps to reduce the demand for virgin material and contribute to the conservation of the global resource base. For internal managers and others interested in the financial condition of the reporting organization, substituting recycled materials can contribute to lowering overall costs of operation.

Table 15 Material consumption indicators

Indicator	Primary data unit [1]	Normalization data unit [2]
Primary Raw Materials (PRM)		
Total PRM consumption	unit amount of PRM	--
PRM intensity (Specific PRM consumption)	unit amount of PRM	(1), (2), or (3)
Increase or decrease in total PRM consumption	unit amount of PRM	--
Absolute change in PRM substitution	unit amount of PRM	--
Relative change of PRM substitution	% [3]	
PRM efficiency	%	
Secondary Raw Materials (SRM)		
Total SRM consumption	unit amount of SRM	--
SRM intensity (Specific SRM consumption)	unit amount of SRM	(1), (2), or (3)
Increase or decrease in total SRM consumption	unit amount of SRM	--
Relative change of increase or decrease in total SRM consumption [4]	%	
SRM valorisation (substitution)	unit amount of SRM	--
Relative change of SRM Valorisation [4]	%	
SRM efficiency [4]	%	
Raw Materials (RM)		
Total RM consumption	tonne SRM	--
RM intensity	tonne SRM	(1), (2), or (3)
Increase or decrease in total RM consumption	tonne SRM	--
Relative change in increase or decrease in total RM consumption	%	
RM valorisation (substitution)	tonne SRM	--
Rate of RM substitution	%	
RM efficiency	%	

[1] Possible unit amounts may include mass or volume

[2] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value
When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[3] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason primary and normalization data units are not specified separately.

[4] In case the baseline condition represents no use of SRM (i.e. no valorisation of SRMs), the denominator for these indicators become zero. Thus these indicators are not applicable to comparison of before and after implementation of IS. Rather, they should be used to assess periodic improvement within an ongoing IS system.

5.3.1.2 Energy Consumption

Energy is a fundamental aspect in resource efficiency. Key energy-related issues include dependency in fossil fuels, greenhouse gas emissions, energy security and dependency as well as cost. Promoting energy efficiency not only cuts fuel dependency but also can reduce costs and greenhouse gas emissions. Energy indicators play a crucial part in monitoring the mid-term and long-term shift towards a low-carbon economy in the EU. For this reason, energy indicators is a part of every sustainability indicator set currently in use globally.

The indicators given in Table 16 cover energy consumption in terms of fuel, thermal energy, electricity, and renewable energy consumption. Although total fuel consumption indicators are provided below, fuel consumption indicators can be adjusted to cover fossil fuels or can be further disaggregated in terms of specific types of energy sources. The set of fuel consumption indicators can be duplicated to reflect consumption of different fossil fuels if utilization trend will be monitored separately.

Table 16 Energy consumption indicators

Indicator	Primary data unit	Normalization data unit [1]
Fuel		
Total fuel consumption	kWh Fuel	--
Fuel intensity (Specific fuel consumption)	kWh Fuel	(1), (2), or (3)
Increase or decrease in total fuel consumption	kWh Fuel	--
Relative change of increase or decrease in total fuel consumption	% [2]	
Fuel substitution [3]	kWh Fuel	--
Relative change of fuel substitution	%	
Fuel efficiency	%	
Thermal Energy (other than direct fuel use)		
Total thermal energy consumption	kWh Thermal energy	--
Thermal energy intensity (Specific thermal energy utilization)	kWh Thermal energy	(1), (2), or (3)
Increase or decrease in total thermal energy consumption	kWh Thermal energy	--
Relative change of increase or decrease in total thermal energy consumption	%	
Thermal energy substitution	kWh Thermal Energy	--
Relative change of Thermal Energy Substitution	%	
Thermal energy efficiency	%	
Electricity		
Total electricity consumption	kWh Electricity	--
Electricity intensity (Specific electricity consumption)	kWh Electricity	(1), (2), or (3)
Increase or decrease in total electricity consumption	kWh Electricity	--
Relative change of increase or decrease in total electricity consumption	%	
Electricity substitution	kWh Electricity	--
Relative change of Electricity Substitution	%	
Electricity efficiency	%	
Renewable Energy		
Total renewable energy consumption	kWh Renewable energy	--
Share of renewable energy consumption	%	
Renewable energy intensity (Specific renewable energy consumption)	kWh Renewable energy	(1), (2), or (3)
Increase or decrease in total renewable energy consumption	kWh Renewable energy	--
Increase or decrease in share of renewable energy consumption	%	
Relative change of increase or decrease in total renewable energy consumption	%	
Total Energy		
Total energy consumption	kWh Energy	--
Total energy intensity (Specific energy consumption)	kWh Energy	(1), (2), or (3)
Increase or decrease in total energy consumption	kWh Energy	--
Relative change of increase or decrease in total energy consumption	%	
Energy substitution	kWh Energy	--
Relative change of energy substitution	%	
Energy efficiency	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason primary and normalization data units are not specified separately.

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[3] This indicator can be used to specify the extend of fossil-fuel substituted by renewable energy source or can be interpreted as the amount of fuel consumption avoided.

5.3.1.3 Exergy Consumption

Exergy is a measure of quality of energy and it can be consumed or destroyed through the operation of any physical or mechanical system. In thermodynamics, the term exergy is used to quantify the amount of work a unit of energy may perform relative to a thermodynamic groundstate (i.e. exergy is useful energy or energy that may theoretically be used to perform work). Here a groundstate is a state of zero theoretical work potential reached when a material or energy stream is in equilibrium with the surrounding environment.

The entropy of a resource allows us to measure the extent to which irreversible dissipation reduces the work potential (i.e. the exergy) of that resource relative to a specified groundstate. As entropy increases at constant enthalpy, exergy decreases [60]. While the groundstates of numerous substances have been estimated, the specification of thermodynamic groundstates for most resources remains highly subjective.

In order to provide a fresh take on energy indicators, exergy-based measures to monitor consumption and recycling are put forward that rely only on the calculation of exergy differentials (i.e. changes due to consumption). Exergy analysis clearly indicates the locations of energy degradation in a process and can therefore lead to improved operation or technology. Exergy analysis can also quantify the quality of heat in a waste stream. A main aim of exergy analysis is to identify meaningful (exergy) efficiencies and the causes and true magnitudes of exergy losses [61].

One way to reduce the resource depletion is to reduce the losses that accompany the transfer of exergy to consumed resources by increasing the efficiency of exergy transfer between resources, i.e., increasing the fraction of exergy removed from one resource that is transferred to another. Exergy efficiency may be thought of as a more accurate measure of energy efficiency that accounts for quantity and quality aspects of energy flows [65].

A general comparison of energy and exergy is given in Table 1.

Table 17 Comparison of energy and exergy [61]

Energy	Exergy
Dependent of properties of only a matter or energy flow, and independent of environment properties	Dependent on properties of both matter and energy flow and the environment
Has values different from zero when in equilibrium with the environment	Equal to zero when in the dead state by virtue of being in complete equilibrium with environment
Conserved for all processes	Conserved for reversible processes and not conserved for real processes (where it is partly or completely destroyed due to irreversibilities)
Can be neither destroyed nor produced	Can be neither destroyed nor produced in a reversible process but is always destroyed (consumed) in an irreversible process
Appears in many forms (i.e. kinetic and potential energy, work , heat) and is measured in that form	Appears in many forms (i.e. kinetic and potential exergy, work , thermal exergy) and is measured in on the basis of work or ability to produce work
A measure of quantity only	A measure of both quantity and quality

Exergy approach was used by Valero et al. (2012) in order to analyse main energy and material exchanges in Kalundborg IS system [63]. The study, based on the thermodynamic modelling of the IS network identified the exergy demand of the flows and analysed irreversibilities with and without IS.

Table 18 Exergy indicators

Indicator	Primary data unit	Normalization data unit [1]
Exergy		
Total exergy consumption	kWh Exergy	--
Exergy intensity	kWh Exergy	(1), (2), or (3)
Increase or decrease in total exergy consumption	kWh Exergy	--
Relative change of increase or decrease in total exergy consumption	% [2]	
Exergy Efficiency	%	
Cumulative exergy demand [3]		

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason primary and normalization data units are not specified separately.

[3] See Section 5.3.2.6 for definition of this life cycle indicator

5.3.1.4 Air Emissions

Various air pollutants released to the environment are associated with global issues including ozone depletion, acidification, eutrophication and most importantly climate change. To limit the impacts of these issues, more concrete steps were taken for ozone depletion, acidification and eutrophication, which does not necessary mean these problems are eradicated. There is still a need for monitoring of certain air emissions such as sulphur and nitrogen oxides. However, most pressing issue related to air emissions is global climate change due to which greenhouse gas (GHG) emission indicators are included in many existing European indicator sets. Air emission indicators seen in Table 19 covers GHG emissions apart from general category of air emissions. While quantifying GHG indicators all GHGs, listed in the definition section, should be considered and all GHG species should be converted to carbon equivalents ($CO_{2\text{-eq}}$). Air emissions on the other hand should be disaggregated based on the industrial activities occurring within the IS network. Selection of indicators for specific air pollutants should be based on sectorial KPIs. For the FISSAC IS network air emissions to be monitored as a part of sectorial KPIs in cement and ceramic industry include NO_x, SO_x, dust, dioxin and furans, volatile organic compounds, hydrogen fluoride.

Table 19 Air emission indicators

Indicator	Primary data unit	Normalization data unit [1]
Greenhouse Gas (GHG) Emissions		
Total GHG emissions	tonne $CO_{2\text{-eq}}$	--
GHG emissions from electricity consumed and purchased	tonne $CO_{2\text{-eq}}$	--
GHG emissions from fuel consumption	tonne $CO_{2\text{-eq}}$	--
GHG emission intensity (Specific GHG emissions)	tonne $CO_{2\text{-eq}}$	(1), (2), or (3)
Increase or decrease in total GHG emissions [2]	tonne $CO_{2\text{-eq}}$	--
Relative change of increase or decrease in total GHG emissions [2]	% [3]	
Change in GHG emission intensity	%	
Carbon footprint	tonne $CO_{2\text{-eq}}$	(1), (2), or (3)
Air Emissions		
Air emissions	tonne pollutant	--
Air emission intensity (Specific air emissions)	tonne pollutant	(1), (2), or (3)
Increase or decrease in air emissions	tonne pollutant	--
Relative change of increase or decrease in air emissions	%	
Change in air emission intensity	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

A common practice in cement industry is to report GHG emissions per ton of clinker, cement and cementitious product separately when needed.

[2] Absolute or relative decrease in GHG emissions can also be named as avoided GHG emissions

[3] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

5.3.1.5 Solid Wastes

Solid waste generation is another basic indicator that is included in many existing indicator sets. Due the difference in impact on the environment the list proposed in Table 20 are grouped as hazardous and non-hazardous solid wastes.

Table 20 Solid waste indicators

Indicator	Primary data unit	Normalization data unit [1]
Hazardous Solid Wastes (HW)		
Total HW generation	tonne	--
HW generation intensity (Specific HW generation)	tonne	(1), (2), or (3)
Increase or decrease in total HW generation	tonne	--
Relative change of increase or decrease in total HW generation	% [2]	
HW recycling	tonne	--
Share of recycled HW	%	
Relative change of HW recycling	%	
Change in HW generation intensity	%	
Non-Hazardous Solid Wastes (NHW)		
Total NHW generation	tonne	--
NHW generation intensity (Specific NHW generation)	tonne	(1), (2), or (3)
Increase or decrease in total NHW generation	tonne	--
Relative change of increase or decrease in total NHW generation	%	
NHW recycling	tonne	--
Share of recycled HW	%	
Relative change of NHW recycling	%	
Change in solid waste generation intensity	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.1.6 By-Products

By-product indicators are in close relation to material consumption indicators, especially ones related to use of SRMs. While SRMs are valorised on the receiving end of the symbiotic material flow, by-product indicators targeting the supply end (i.e. waste/by-product generator). The reason for including second set of indicators for a similar purpose is the possibility of losing some portion of by-products as residues if processing is required before by-products can be valorised as SRM. In this case, by-product generation on the supply end should be monitored independently. Furthermore, this set of indicators provide a more detailed picture of relation between by-products and the processes generating them.

Table 21 By-product indicators

Indicator	Primary data unit	Normalization data unit [1]
By-products		
Total by-product generation	tonne	--
By-product generation intensity	tonne	(1), (2), or (3)
Increase or decrease in total by-product generation	tonne	--
Relative change of increase or decrease in total by-product generation	% [2]	
By-product recycling	tonne	--
Relative change of by-product recycling	%	
Change in by-product generation intensity	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.
[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.2 Life Cycle Indicators

The life cycle indicators, LCA indicators in particular, presented in this Section are used to carry out quantitative assessments for different aspects of environmental issues similar to the indicators listed in the previous sub-section. The main difference between the life cycle indicators and the proposed indicators in tables above is mainly the system boundaries for which the assessment is done. The environmental and economic indicators already discussed follow a gate-to-gate approach, where date required for quantification can be simply obtained via material and energy flow analyses within the confines of the company. However, life cycle indicators, quantified either for the product or the production proses, use a wider and holistic scope covering the life cycle the product or process.

This section aims to provide introductory information on life cycle indicators covering LCA and LCC studies. LCA indicators (i.e. impact assessment categories) should be selected on a case-by-case basis based on the relevance. For this purpose, an in-depth analysis of the functional system is required. Therefore, life cycle indicators given below is a short list of most relevant indicators for the FISSAC Project. In a subsequent work in FISSAC (WP3: Product Eco-design and Certification), the list of relevant life cycle indicators will be finalized. Detailed estimation methodologies will also be provided in the deliverables of WP3.

5.3.2.1 Abiotic resource depletion

Abiotic resource depletion can be handled in consideration of two perspectives, abiotic depletion of fossil fuels and abiotic depletion of mineral resources [64]. The term fossil fuel refers to a group of resources that contain hydrocarbons. The group ranges from volatile materials like methane, to liquid petrol, to non-volatile materials like anthracite coal [65].Unit of quantification for abiotic depletion – fossil fuels is kg oil-eq/FU. In additional to fossil fuels used for producing electricity, demand occurs due to direct use of fossil fuels in vehicles during transportation. On the other hand, abiotic resource depletion is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation [66].

5.3.2.2 Water footprint or water depletion

Water footprint and water depletion indicators both aim to address the water consumption issue under resource efficiency, with methodological difference. Water depletion category provides a simple water budget in terms of total amount of water consumed within the system boundaries. Water footprint, on the other hand, is one of the family of environmental footprints, which involve water quality in addition to water quantity. ISO 14046 Standard defines water footprint as a set of metric(s) that quantify(ies) the potential environmental impact related to water use. It provides the information to which extent a product, service or company is affecting ecosystems and the society, through the use of water [69].

Water footprint can be estimated in terms of:

- o Blue Water Footprint: The amount of surface water and groundwater required (evaporated or used directly) to make a product.
- o Green Water Footprint: The amount of rainwater required (evaporated or used directly) to make a product.
- o Grey Water Footprint: The amount of freshwater required to mix and dilute pollutants enough to maintain water quality according to certain standards (like the ones established in the US Clean Water Act) as a result of making a product [70].

Furthermore, ISO water footprint framework provides a set of possible indicators to measure scarcity and available issues:

- o Water scarcity footprint: this is the simplest indicator which addresses only water scarcity. It is a basic calculation done by multiplying water consumptions by their respective water scarcity indices.

- o Water availability footprint: this is a more complex indicator addressing only water resources depletion again. It uses a more complex definition of the water scarcity footprint as it accounts for the reduced availability of water due to water pollution.
- o Water footprint: a water footprint is defined as a set of indicators covering environmental impact of water consumption AND pollution. Pollution is usually addressed in standard LCA though indicators like eutrophication, acidification and ecotoxicity .

5.3.2.3 Carbon footprint or Global climate change/Global warming potential

GHG emissions and resulting global climate change issue is monitored through indicators including carbon footprint, global climate change potential and global warming potential. All of these indicators report total GHG emissions in terms of carbon dioxide equivalents. The methodologies of estimation are outlined in ISO 14040, 14044 and 14067 Standards. Intergovernmental Panel on Climate Change is periodically releasing the characterisation factors for conversion of GHG emissions to carbon dioxide equivalents.

Carbon footprint studies considers direct onsite emissions (Tier 1), emissions embodied in purchased energy (Tier 2), and all indirect emissions not covered under Tier 2.

5.3.2.4 Land occupation and transformation

Although there are many links between the way land is used and the loss of biodiversity, there are two widespread mechanisms:

1. occupation of a certain area of land during a certain time;
2. transformation of a certain area of land from its original function.

Both mechanisms can be combined, often occupation follows a transformation, but often occupation occurs in an area that has already been converted (transformed) [65]. The unit of quantification for land occupation is m^2 representing the total area used whereas the unit of quantification for land transformation is m^2.yr representing the total amount of area and duration of occupation both per a functional unit. For indicator based assessment in the FISSAC Project, this functional unit is equivalent to the normalization data.

5.3.2.5 Cumulative energy demand (Embodied energy)

The CED represents the direct and indirect energy use, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials. It is often measured from cradle to (factory) gate, cradle to site (of use), or cradle to grave (end of life). The total CED is composed of the fossil cumulative energy demand (i.e., from hard coal, lignite, peat, natural gas, and crude oil) and the CED of nuclear, biomass, water, wind, and solar energy in the life cycle [72]. Unit of quantification for CED is MJs/functional unit (FU). CED provides a basis for comparison between different products with the same function and is commonly utilized for reporting environmental performance of construction materials.

5.3.2.6 Cumulative exergy demand

Cumulative exergy demand specifies the amount of total exergy removed from nature to provide a product, summing up the exergy of all resources required. CExD assesses the quality of energy demand and includes the exergy of energy carriers as well as of non-energetic materials. Exergy, being defined as the quality of energy, is expressed in terms of MJ in the same way with energy.
The impact category indicator is grouped into the eight resource categories:

1. fossil, nuclear,
2. hydropower,
3. biomass,
4. other renewables,

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Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

5. water,
6. minerals, and
7. metals.

The assignment of the adequate type of exergy depends on resource use:

- Chemical exergy is applied on all material resources, for biomass, water and fossil fuels (i.e. all materials that are not reference species in the reference state)
- Thermal exergy is applied for geothermy, where heat is withdrawn without matter extraction
- Kinetic exergy is applied on the kinetic energy in wind used to drive a wind generator
- Potential exergy is applied on potential energy in water used to run a hydroelectric plant
- Nuclear exergy is applied on nuclear fuel consumed in fission reactions
- Radiative exergy is applied on solar radiation impinging on solar panels [66].

5.3.2.7 Ecological footprint

The Ecological Footprint (EF) concept introduced by Wackernagel and Rees is an analysis of the direct effects of urban development on the planet. The planet's biocapacity is represented by the productive land areas including forests, pastures, cropland and fisheries. The carrying capacity is compared with the human demand on nature. The EF is the productive area required to provide renewable sources any given activity is using to absorb its impacts. The productive area currently occupied by human infrastructure is also included in this calculation, since built-up land is not available for resource regeneration [67].

The computation is the sum of direct and indirect land occupation (hectares) through the life cycle, which includes nuclear energy use and CO_2 emissions from fossil energy use [73]. Unit:[ha/(m2*a)]

$$\text{Ecological Footprint (EF)} = \text{EF}_{\text{direct}} + \text{EF}_{\text{CO2}} + \text{EF}_{\text{nuclear}}$$

5.3.2.8 Life cycle cost

LCC is an important economic analysis used in the selection of alternatives that impact both pending and future costs. It compares initial investment options and identifies the least cost alternatives for a twenty year period [68]. LCC incorporates regular cost items with environmental costs including end-of-life costs.

5.3.3 Economic Indicators

5.3.3.1 Product Quantity

Product quantity is one of the parameters that are monitored in every industrial facility. Not only it is the basis for the economic income to be gained by the company, it also gives an indication on capacity utilization in the plant. So far product quantity (or production volume) were used a normalization data for calculation of intensity indicators.

Table 22 Product quantity indicators

Indicator	Primary data unit	Normalization data unit [1]
Product Quantity		
Total product quantity	tonne	--
Increase or decrease in total product quantity	tonne	--
Relative change of increase or decrease in total product quantity	% [2]	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.3.2 Turnover

Table 23 Turnover indicators

Indicator	Primary data unit	Normalization data unit [1]
Turnover		
Total turnover	€	--
Increase or decrease in total turnover	€	--
Relative change of increase or decrease in total turnover	% [2]	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.3.3 Net Value Added

Table 24 Net value added indicators

Indicator	Primary data unit	Normalization data unit [1]
Net Value Added		
Total net value added	€	--
Increase or decrease in total net value added	€	--
Relative change of increase or decrease in total net value added	% [2]	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.3.4 Operational Cost (OPEX)

Table 25 Operational Cost (OPEX) indicators

Indicator	Primary data unit	Normalization data unit [1]
Material Cost		
Total material cost	€	--
Specific material cost	€	(1), (2), or (3)
Increase or decrease in total material cost	€	--
Relative change of increase or decrease in total material cost	% [2]	
Relative change in specific material cost	%	
Water Cost		
Total water cost	€	--
Specific water cost	€	(1), (2), or (3)
Increase or decrease in total water cost	€	--
Relative change of increase or decrease in total water cost	%	
Relative change in specific water cost	%	
Energy Cost		
Total energy cost	€	--
Specific energy cost	€	(1), (2), or (3)
Increase or decrease in total energy cost	€	--
Relative change of increase or decrease in total energy cost	%	

Relative change in specific energy cost	%	
Land Use Cost		
Total land use cost	€	--
Specific land use cost	€	(1), (2), or (3)
Increase or decrease in total land use cost	€	--
Relative change of increase or decrease in total land use cost	%	
Relative change in specific land use cost	%	
Labour Cost		
Total labour cost	€	--
Specific labour cost	€	(1), (2), or (3)
Increase or decrease in total labour cost	€	--
Relative change of increase or decrease in total labour cost	%	
Relative change in specific labour cost	%	
Maintenance Cost		
Total maintenance cost	€	--
Specific maintenance cost	€	(1), (2), or (3)
Increase or decrease in total maintenance cost	€	--
Relative change of increase or decrease in total maintenance cost	%	
Relative change in specific maintenance cost	%	
Total Operational Cost (OPEX)		
Total operational cost	€	--
Specific operational cost	€	(1), (2), or (3)
Increase or decrease in total operational cost	€	--
Relative change of increase or decrease in total operational cost	%	
Relative change in specific operational cost	%	
Environmental Cost Savings		
Total waste disposal cost savings	€	--
Specific waste disposal cost savings	€	(1), (2), or (3)
Increase or decrease in total waste disposal cost savings	€	--
Relative change in increase or decrease in total waste disposal cost savings	%	
Relative change in specific waste disposal cost savings	%	
Total wastewater treatment cost savings	€	--
Specific wastewater treatment cost savings	€	(1), (2), or (3)
Increase or decrease in total wastewater treatment cost savings	€	--
Relative change in increase or decrease in total wastewater treatment cost savings	%	
Relative change in specific wastewater treatment cost savings	%	
Total cost savings due to avoided GHG emissions	€	--
Specific cost savings due to avoided GHG emissions	€	(1), (2), or (3)
Increase or decrease in total cost savings due to avoided GHG emissions	€	--
Relative change in increase or decrease in total cost savings due to avoided GHG emissions	%	
Relative change in specific cost savings due to avoided GHG emissions	%	
Total cost savings due to avoided regulatory fines	€	--
Specific cost savings due to avoided regulatory fines	€	(1), (2), or (3)
Increase or decrease in total cost savings due to avoided regulatory fines	€	--
Relative change in increase or decrease in total cost savings due to avoided regulatory fines	%	
Relative change in specific cost savings due to avoided regulatory fines	%	
Revenues as a Result of IS activities		
Total revenues from by-product sales	€	--
Specific revenues from by-product sales	€	(1), (2), or (3)
Increase or decrease in total revenues from by-product sales	€	--

Relative change in increase or decrease in total revenues from by-product sales	%
Relative change in specific revenues from by-product sales	%

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.3.5 Capital Cost (CAPEX) and Investment Indicators

Table 26 Capital Cost (CAPEX), investment indicators and their units

Indicator	Primary data unit	Normalization data unit [1]
Material Cost		
Total capital cost (for IS applications)	€	--
Specific capital cost (for IS applications)	€	(1), (2), or (3)
Net present value of the investment	€	--
Return on Investment (ROI)	years	--
Internal Rate of Return on Investment	% [2]	--

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value

When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.

[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.3.4 Social Indicators

Industrial symbiosis practices provide social benefits for industries as well as their neighbouring communities. These benefits include human capital achieved through employment, shared health and safety practices, lower staff turnover, and more innovative industrial practices. Furthermore, IS initiatives are expected to boost local economy and growth, create new business opportunities, help transfer and knowledge and new skills, and contribute to the sense of community. Social indicators identified to be relevant to the FISSAC Project is provided in Table 27.

Table 27 Social indicators

Indicator titles	Specific indicators
Job creation and retention	Number of new jobs Average duration of number of years of employment at the same company
Creation of IS	Number liaisons (number of connection between companies) Extend of shared facilities
Social responsibility	Size of the union (Share of union membership among the workers) Number of focus groups or records from local focus groups
Lifelong learning	Number of trainings provided Total hour of trainings per employees Share of training in total workable hours Cost of training and education programmes per employee
Health and safety at work	Number of accidents in a year Average number of days without an accident
Rate of community participation	Number of projects funded
Level of social acceptance	% of the local public in support of the IS initiative % of the key local stakeholders and decision makers in support of the IS Numbers of articles published creating positive and negative publicity
Community development	Share of profits dedicated for charity
Innovation and investment in R&D	Number of patents Number of technologies transferred

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grant agreement № 642154.

	Expenditure of resource related R&D Number of environmental certificates obtained

5.3.5 Circularity Indicators

5.3.5.1 Environmental impact momentum

The rate between inbound and outbound momentum determines the symbiosis level. In a perfect symbiosis, there are large amounts of inbound by-product and no outbound by-product exiting the IS network, so that the total amount of by-product is equal to the amount of inbound by-product The higher the internal flow of the inbound by-product and the lower the external flow of by-product, the higher is the value of the symbiosis indicator. Therefore, by comparing the amount of outbound by-product and the amount of inbound by-products over time, it is possible to monitor the evolution of symbiosis within a network [74].

$$EIM = {EIM_i}/{(1 + EIM_o)} = \frac{\sum_{w=1}^{n}(AiP_w * DiP_w)}{1 + \sum_{w=1}^{n}(AoP_w * DoP_w)}$$

Where: EIM_i: Environmental impact momentum inbound
EIM_o: Environmental impact momentum outbound
n: number of by-products
w: type of by-product
AoP: amount of outbound by-products
AiP: amount of inbound by product
DiP: degree of inbound by-product
DoP: degree of outbound by-product

5.3.5.2 Utility

Utility accounts for the length of a product's use phase (lifetime) and intensity of use (function). The length of useful lifetime can be defined as the ratio of lifetime of the product in question to average lifetime of the similar products with same function on the market. The intensity reflects the extent to which a product is used to its full capacity and can be considered as the number of times it serves it function before it reaches the end-of-life stage, which is achieved through recycling. Therefore, intensity should not be confused with repetitive undertaking of a task before the product becomes a waste. Similar to useful lifetime, intensity can be calculated by taking the ratio of number of times a product serves its function before it reaches the definitive end-of-life to the same number calculated for the average of the products on the market [18]. Utility is calculated as

$$X = \frac{L}{L_{av}} * \frac{U}{U_{av}}$$

Where L: lifetime of the product
L_{av}: average lifetime of the similar products on the market
U: number of times function served over the lifetime
U_{av}: average number of times function is served over the lifetime by similar products on the market

While using this indicator, is important to make sure that any given effect is only considered once – either as an impact on lifetimes, or on intensity of use - but not both [18] .

5.3.5.3 Environmental cost effectiveness

This indicator is to evaluate and identify the least cost option for meeting a specific physical outcome like conventional Cost Effectiveness Analysis [75]. The performance assessment should be done via an environmental effectiveness metric that measures the economic and environmental (CO_2 savings) costs of a particular configuration of a prescribed scenario: Unit: [t CO_2 / €]

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$$\text{Environmental cost effectiveness (ECC)} = \frac{(\text{Annual CO2 emission savings })}{(\text{Annual cost of IS})}$$

$$\text{Environmental cost effectiveness}_{\text{n}} = \frac{(\text{Annual CO2 emissions}_{\text{Baseline}}) - (\text{Annual CO2 emissions}_{\text{Scenario n}})}{(\text{Annual cost of the investment})}$$

$$\text{Annual cost of IS} = \frac{\text{Life Cycle OPEX and CAPEX}}{\text{Life cycle duration}}$$

5.3.6 Network Indicators

The indicators studied in this section are related to the positioning, directional relations and amount of transactions of the actors in a network or graph. Representing a problem as a graph can provide new points of view and additional tools for solving the problem. The mathematical quantification background relies on graph theory is widely used for social network analyses (SNA). The SNA related indicators have been found directly applicable to Industrial Symbiosis analyses.

The section aims to provide a brief description of the graph and network terminology, followed by a set of relevant indicator and metric definitions. The metrics defined do not aim to deliver the whole set of graph theory related quantification approaches, however, those that are found to be relevant and useful for IS networks. For a thorough understanding on the mathematical background, further reading on the topic would be recommended. The individual of composite utilisation of the henceforth identified metrics in the FISSAC project and platform will be further discussed within the WP6 Software requirement analyses studies.

5.3.6.1 Basic Network Terminology

Vertices or nodes are the units or actors in a network (or a graph or a system)

Edges (Arcs), are the ties or connections between nodes. They can be directed or

Network, defines the system that includes a finite set of nodes and a set of directed arcs

Flows are the amount of material or energy transferred from one node to another

Flow Conservation, indicates that a flow may be neither created nor destroyed in the network. The concept relies on the Kirchoff Laws and can be used as a core constraint in minimal cost network flow equations

Adjacent nodes, are nodes two nodes that are directly connected by an arc

Path, is a sequence of arcs, in which the initial node of each arc is the same as the terminal node of the preceding arc in the sequence. The terminology is used for shortest path problem solutions. A **chain** is similar structure to an arc, except that not all arcs are necessarily directed toward a final terminal node

Degree, denotes the number of edges (arcs) incident on a node

- In-degree: Number of edges entering
- Out-degree: Number of edges leaving
- Degree = Degree = indeg + outdeg

5.3.6.2 Centrality

This measure is an indicator of the position of different nodes in the network and the relevance of the role played by each of them. Simply, serves as a measure of how many connections one node has to other nodes.

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Degree centrality, measures the number of direct links a node has. This measure assumes that the more direct connections a node has, the stronger is its position in the network. Actors who have more ties may have multiple alternative ways and resources to reach goals—and thus be relatively advantaged.

Betweenness centrality, measures the ability of a node to pass on information and connect nodes. Therefore, according to this indicator, the identification of key actors will depend on their influence on gaining or cutting access to other nodes in the network.

Closeness centrality, looks to the distances between nodes in a network. Shorter distances to other nodes result in a higher score in closeness.

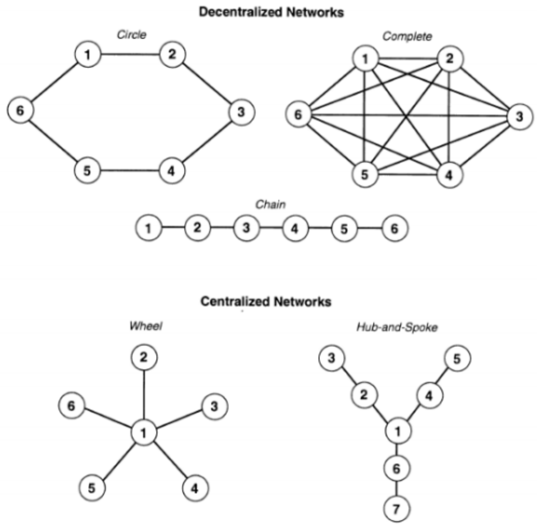

Figure 7 Centralized and decentralized networks

5.3.6.3 Betweenness and Closeness

Betweenness is a measure of the extent to which a node is connected to other nodes that are not connected to each other. It is a measure of the degree to which a node serves as a bridge. This measure can be calculated in absolute value, as well as in terms of a normed percentage of the maximum possible betweenness that an actor or node could have had

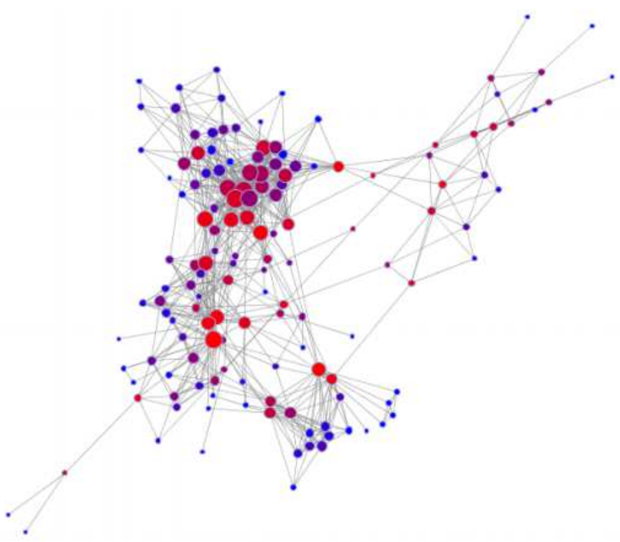

Figure 8 Example network: nodes are sized by degree, and colored by betweenness [76]

Closeness is a measure of the degree to which an individual is near all other individuals in a network. It is the inverse of the sum of the shortest distances between each node and every other node in the network. Closeness is the reciprocal of farness. **Nearness** can also be standardized by norming it against the minimum possible nearness for a graph of the same size and connection

5.3.6.4 Reciprocity

This notion of reciprocity fully applies to IS networks. IS literature has emphasised that companies in IS networks are engaged in mutually beneficial exchanges. However, when analysing concrete IS dyads, cooperative links also seem to occur when no direct pay-back is attached to them, analysed on a single transaction basis. In this last case, the rationale of the behaviour has to be linked to more subtle and inter-temporal framework as the one presented above, taking into account generalised reciprocity and network balancing. Distinguish between symmetric (non-directive) relationships and asymmetric relationships.

When characterising IS networks, attention must be paid to the level of **embeddedness** of its ties, as it might be a good indicator of the performance of the network.

5.3.6.5 Intensity

Intensity is the measure of the frequency of contact in a unit of time or a proxy of the content value of the exchange

5.4 Additional Indicators Relevant to Other IS Networks

5.4.1 Water Consumption

Water consumption can be defined as “the sum of all water drawn into the boundaries of a production plant from all sources (including surface water, ground water, rainwater, and municipal water supply) for any use over the course of the reporting period” [15]. While utilization of water from different sources can be monitored, reporting the total volume of water withdrawn by source contributes to an understanding of the overall scale of potential impacts and risks associated with water use. While industrial activities impact water quality and quantities available, scarcity of water can also have an effect on production processes that rely on large amounts of water. In regions where water sources are highly restricted, the organization’s water consumption patterns can also influence relations with other stakeholders [15].

The rate of water reuse and recycling can be a measure of efficiency and can demonstrate the success of the organization in reducing total water withdrawals and discharges. Increased reuse and recycling can result in a reduction of water consumption, treatment, and disposal costs. The reduction of water consumption through reuse and recycling can also contribute to local, national, or regional goals for managing water supplies [15].

List of water consumption indicators are listed in Table 28. Similar to SRM consumption, recycled water can be used as process water or for other purposes (grey water). Indicator related to the recycled water use indicator given along with the set of wastewater indicators. Purpose of groundwater and surface water substitution indicators is to reflect the impact of such a practice. Still recycled water consumption should be considered when overall water utilization is being studied. Any other water sources such as rain water should be included in the assessment whenever applicable. The same set of indicators provided for ground- or surface water can be adapted to the new water source. Similarly, if use of ground- or surface water is not being exercised at a plant, those indicators should be omitted from the assessment.

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Table 28 Water consumption indicators

Indicator	Primary data unit	Normalization data unit [1]
Groundwater (GW)		
Total GW consumption	m^3 GW	--
GW intensity (Specific GW consumption)	m^3 GW	(1), (2), or (3)
Increase or decrease in total GW consumption	m^3 GW	--
Relative change of increase or decrease in total GW consumption	% [2]	
GW substitution	m^3 GW	--
Relative change of GW Substitution	%	
GW efficiency	%	
Surface Water (SW)		
Total SW consumption	m^3 SW	--
SW intensity (Specific SW consumption)	m^3 SW	(1), (2), or (3)
Increase or decrease in total SW consumption	m^3 SW	--
Relative change of increase or decrease in total SW consumption	%	
SW substitution	m^3 SW	--
Relative change of SW substitution [3]	%	
SW efficiency	%	
Overall water utilization		
Total water consumption	m^3 water	--
Water intensity (Specific water consumption)	m^3 water	(1), (2), or (3)
Increase or decrease in total water consumption	m^3 water	--
Relative change of increase or decrease in overall water consumption	%	
Water substitution	m^3 water	--
Relative change of SW substitution	%	
Water efficiency	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value
When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.
[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason primary and normalization data units are not specified separately.

5.4.2 Wastewater Generation

Assessment of wastewater generation should cover both the amount of wastewater treated to the receiving bodies after treatment as well the amount of wastewater recycled for different purposes such as process water, grey water, irrigation water etc. The list of indicators in Table 29 are strongly related to water indicators (Section 5.4.1). In addition to wastewater generation, a pollutant load indicator is added to the list, which provides an indication about the wastewater quality.

Table 29 Wastewater indicators

Indicator	Primary data unit	Normalization data unit [1]
Wastewater		
Total wastewater generation	m^3	--
Wastewater generation intensity (Specific wastewater generation)	m^3	(1), (2), or (3)
Increase or decrease in total wastewater generation	m^3	--

Relative change of increase or decrease in total wastewater generation	% [2]	
Wastewater recycling	m^3	--
Ratio of the recycled wastewater	%	
Relative change of wastewater recycling	%	
Change in wastewater generation intensity	%	
Pollutant load in wastewater (Chemical oxygen demand – COD)	mg	volume of wastewater

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value
When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.
[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.4.3 Waste Heat

In IS networks materials are not the only flows that can be valorised. In many cases, energy from waste heat can be extracted and converted to useful forms. Therefore, indicators in Table 30 aim to provide information on energy flows that can be valorised in energy symbiosis or material/energy symbiosis systems.

Table 30 Waste-heat indicators

Indicator	Primary data unit	Normalization data unit [1]
Waste heat		
Total waste heat generation	kWh	--
Waste heat generation intensity	kWh	(1), (2), or (3)
Increase or decrease in total waste heat generation	kWh	--
Relative change of increase or decrease in total waste heat generation	% [2]	
Waste heat valorisation	kWh	--
Relative change of waste heat recycling	%	
Change in waste heat generation intensity	%	

[1] Units of possible denominators: (1) per product quantity (mass, volume, energy or area), (2) per turnover, (3) per net added value
When product amount is used for normalization, any possible change in product yield should be observed. Even if the raw material consumption is not changed, process optimization techniques enhancing productivity may result in an improvement in indicators values.
[2] All relative change indicators, which are reported as %, are calculated with respect to a baseline situation. For this reason, primary and normalization data units are not specified separately.

5.5 Interpretation of indicators and aggregation

5.5.1 Composite indicators and aggregation

This section covers an overview of various indices, methodologies, initiatives and tools, which are practically implemented to measure sustainable resource management and resource optimization problems. Attempts have been made to compile the information about how the indices were formulated using normalisation, weighting, aggregation. It has been found that normalisation and weighting of indicators – which in general are associated with subjective judgments – reveal a high degree of arbitrariness without mentioning or systematically assessing critical assumptions. As to aggregation, there are scientific rules, which guarantee consistency and meaningfulness of composite indices.

Indices and rating systems are subject to subjectivity despite the relative objectivity of the methods employed in assessing the sustainability. The multi-dimensionality of composite indices and rating systems represent one of their main advantages. Indices represent aggregate measures of a combination of complex development phenomena. Composite indices generally combine measures of ends and means. In respect of method and technique, composite indexing is relatively complex.

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Although there are various international efforts on measuring sustainability, only few of them have an integral approach taking into account environmental, economic and social aspects. In most cases the focus is on one of the three aspects. Although, it could be argued that they could serve supplementary to each other, sustainability is more than an aggregation of the important issues, it is also about their inter-linkages and the dynamics developed in a system. This point will be missing if tried to use them supplementary and it is one of the most difficult parts to capture and reflect in measurements.

Composite indicators may send misleading, non-robust policy messages if they are poorly constructed or misinterpreted. Sub-indicators should be selected meticulously. Choice of model, weighting mechanism and treatment of missing value also play a predominant role while construction of framework. Sometimes index increases the quantity of data needed because data are required for all the sub-indicators and for a statistically significant analysis. There are two critical issues, i.e. correlation among indicators and compensability between indicators must be taken into consideration.

A composite constructed on the basis of underlying indicators with high internal correlation will give a very robust index, whose values and ranking are moderately affected by changes in the selection of weights, the normalisation method and other steps involved in the analysis.

Indicators should be selected and negotiated by the appropriate communities of interest. Thus, composite indicators must be constructed within a coherent framework. This would ensure that the specific parameters involved in the evaluation process could change through time according to the interests of the particular stakeholders involved in the construction of the indicators.

5.5.2 Interpretation of indicator based assessment results

For some of the indicators the issue of interest is not the change in one single trend but in the relationship of two trends. One of these two trends is usually an economic variable, and the other one an environmental variable that shows the environmental pressures exerted by the economic activity. For example, this is the case when analysing trends in resource productivity, where the focus is put on the relationship between the trends in GDP and material consumption. These are called ‘decoupling’ indicators because they show the strength of the link (or the ‘coupling’) between the economic and the environmental variable. As seen in Figure 9, in relation to sustainable development, the aim is to achieve a ‘decoupling’ of these two variables, so that continued economic growth does not lead to a further increase in environmental degradation [21].

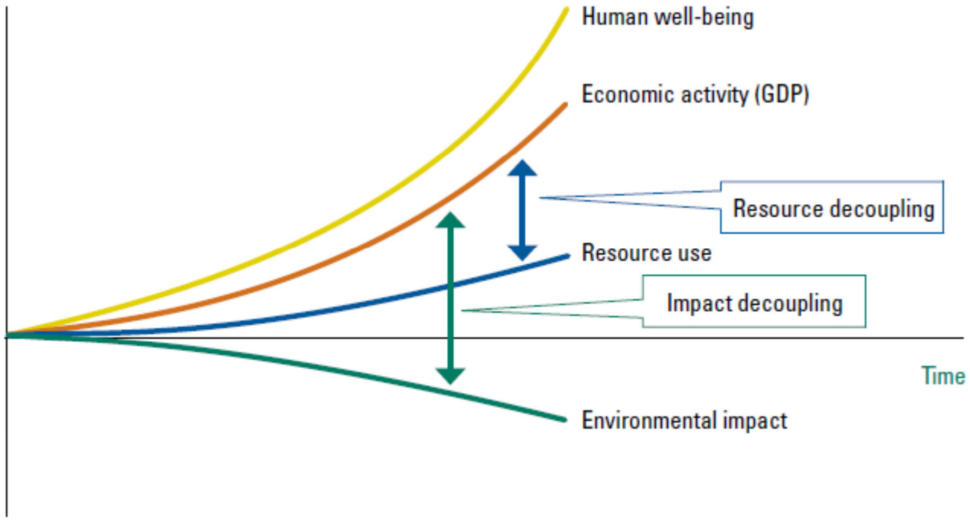

Figure 9 Decoupling of resources and environmental impacts through resource efficiency [78]

Sustainable industrial practices are expected to create resource and impact decoupling. Resource decoupling can be defined as reducing use of primary resources per unit of economic activity or dematerialization. Resource decoupling leads to an increase in efficiency which makes the efficiency indicators highly relevant for interpretation of decoupling. On the other hand, impact decoupling calls for increasing economic output while reducing adverse environmental impacts arising from the extraction of resources and waste generation. Life cycle indicators in general are widely used to assess impact decoupling [78].

It is important to note that the evaluation method used for this monitoring report does not look at the correlation of the two underlying indicators (pressure and driving force) but at the development of the pressure variable in relation to the development of the driving force variable. Overall, the evaluation is considered favourable if the (environmental) pressure variable is decreasing and unfavourable if it is increasing. Depending on the direction and magnitude of change in the pressure variable in relation to the driving force, there are four different degrees of decoupling and thus four evaluation categories:

- Absolute decoupling: The situation when the pressure on the environment decreases while the (economic) driving force increases is considered to be ‘clearly favourable’. This is also the case when the driving force is decreasing but at a slower pace than the decrease in the pressure variable. These situations represent ‘absolute decoupling’ between the driving force (economic) variable and the pressure (environmental) variable.
- Favourable relative decoupling: When the pressure on the environment decreases but at a slower pace than the decrease in the economic variable, the situation is referred to as ‘favourable relative decoupling’ and is evaluated as ‘moderately favourable’.
- Unfavourable relative decoupling: When the environmental pressure increases but at a slower pace than the increase in the driving force, the situation is referred to as ‘unfavourable relative decoupling’. It is evaluated as ‘moderately unfavourable’ because of the increase in the environmental impacts.
- No decoupling: When the pressure on the environment increases at the same or higher rate than the growth of the economic variable, or if the pressure on the environment increases while the economic variable regresses, it is referred to as a situation of ‘no decoupling’ and is evaluated as ‘clearly unfavourable’ [21].

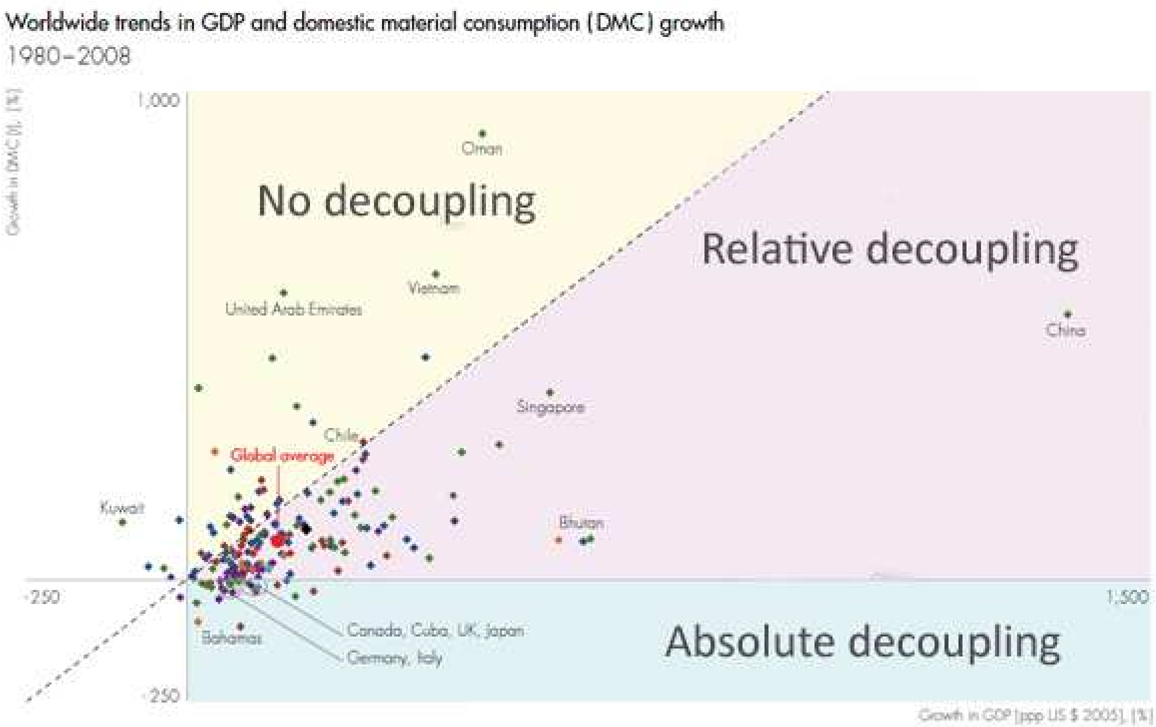

Table 31 An example for interpretation of decoupling through indicators [79]

6 CONCLUSIONS

Purpose of the report is to provide existing IS and sustainability related indicators, establish a scope and methodology for the selection of indicators relevant to the FISSAC Project, propose a list of indicators to be utilized in the following activities in the project and provide indicator definitions.

The indicators proposed in this report cover baseline and impact indicators, which represent a “snap shot” of environmental, economic, or social indicators at a given time and change in baseline indicators over a period of time respectively. Basic indicators are selected rather than composite indices to provide higher ease of use by different stakeholders of the IS networks and to avoid possible problems with aggregation. Exception to use of basic indicators is the life cycle indicators such as water, carbon or ecological footprint. In addition to basic environmental, economic and social indicators and life cycle indicators, network strength analysis indicators are proposed to facilitate establishment and monitoring of the IS network.

Among the set of indicators proposed for the FISSAC network are environmental, economic, social, network analysis and circularity indicators. Under environmental indicators, material and energy related indicators are found to be highly relevant to the FISSAC IS network as energy and material intensive sectors are represented in the FISSAC network. Material indicators address utilization of primary and secondary raw materials separately. In relation to SRM valorisation, indicators on solid waste and by-product generation are also present in the proposed list of FISSAC indicators. SRM, solid waste and by-product indicators provide insight on the waste exchanges on receiving and supplying end of the flows. On the other hand, energy indicators cover fuel consumption, energy utilized from renewable sources, use of thermal energy etc. In order to account for the quality of energy, exergy indicators are also proposed both in terms of basic indicators and as a part of life cycle indicators in the form of energy and exergy embedded in the final product. Air emissions, in particular GHG emissions constitute to a portion of outflow related indicators. Another important group of environmental indicators, termed as life cycle indicators, aim to go beyond simple input/output quantities and provide an insight on the impacts of consuming the inputs and creating emissions on the environment. These indicators share a similar scope with the environmental indicators based on material and energy flows.

Economic indicators cover important topics including product quantity, turnover, net value added, as well as operational and capital costs. Among these, the first three can be used as stand-alone indicators or can be used for normalization of other indicators to obtain specific (or intensity) indicators.

Finally, the range of social indicators included in the proposed list are based on the possible social benefits of IS. Main criteria of selection was the ability to quantify these social aspects as the list of the indicators suggested in this deliverable are mainly limited to quantitative indicators to minimize subjectivity of analysing qualitative aspects.

Other indicators studied under Task 1.4 do not fall strictly under the categories of environmental, economic or social indicators. These indicators include circularity indicators and network indicators. These aim to assess how well the IS network is established in terms of network strength and how well the established network responds to “circularity” criteria and needs.

The list of indicators presented in Section 5 can be tailored for use in IS network other than the construction value chain IS initiative studied in FISSAC Project. The list of indicators can be streamlined or indicator groups such as air emissions can be further disaggregated on a case-to-case basis during the indicator based assessment. Table 32 summarize the proposed indicators to the FISSAC Project.

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Table 32 Proposed indicators for the FISSAC Project

	Indicators	Including	
ENVIRONMENTAL INDICATORS	*Material consumption*	PRM consumption	Overall raw material consumption
		SRM consumption	
	Energy consumption	Fuel consumption	Overall energy consumption
		Thermal energy consumption	
		Electricity consumption	
		Renewable energy consumption	
	Exergy		Overall exergy consumption
	Air emissions	GHG emissions	Air emissions
		Emissions of specific air pollutants	
	Solid waste generation	Hazardous wastes	Total solid waste generation
		Non-hazardous wastes	
	By-products		
	Life cycle indicators	Abiotic resource depletion	
		Water depletion (water footprint)	
		Global warming potential (carbon footprint)	
		Land occupation and transformation	
		Cumulative energy demand	
		Cumulative exergy demand	
		Ecological footprint	
		Life cycle cost	
ECONOMIC INDICATORS	*Product quantity*		
	Turnover		
	Net value added		
	OPEX	Material cost	Total OPEX
		Water cost	
		Energy cost	
		Land use cost	
		Labour cost	
		Maintenance cost	
		Environmental cost savings	
		Revenues as a result of IS activities	
	CAPEX		Total CAPEX
SOCIAL INDICATORS	*Job creation and retention*		
	Creation of IS		
	Social responsibility		
	Lifelong learning		
	Health and safety at work		
	Rate of community participation		
	Level of social acceptance		
	Community development		
	Innovation and investment in R&D		
CIRCULARITY IDICATORS	*Environmental impact momentum*		
	Utility		
	Environmental cost effectiveness		
NSA	*Betweenness and closeness*		
	Reciprocity		
	Intensity		

The indicator based assessment in FISSAC Project shall lead to evaluation of success of the IS initiative. The results should be interpreted to reveal the extent of decoupling created by IS and analyse the benefits created. These benefits were already outlined in D1.4: Social strategies for FISSAC: Definition of target social groups. The indicators proposed in this deliverable corresponding to these benefits can be seen in Table 33.

Table 33 Monitoring benefits of IS with indicators

For communities and local authorities	Possible indicators that can be linked to these benefits
Boost local economy and growth	Job creation and retention, revenues as a result of IS activities
Local business opportunities	Creation of IS
Improved health for citizens and workers	Health and safety at work
Knowledge transfer and new skills	Lifelong learning
Enhanced quality of life	These can all be quantifies through investments and charity programmes as cooperation with the local community; reduced traffic, noise, air pollution.
Improved aesthetics	
Improved local environment	
Reduced cost for waste disposal	Environmental cost savings
'Sense of community'	Rate of community participation, community development, level of social acceptance
For the environment	**Possible indicators that can be linked to these benefits**
Improved air quality and reduced pollution	Air emissions, Solid waste generation
Ecosystems protection	Ecological footprint, carbon footprint, land occupation and transformation, global warming potential
Avoided water use	Water consumption, water efficiency, water footprint
More efficient use of resources	All resource (material and energy) efficiency indicators
Waste reduction	Waste generation, avoided emissions
Reduced carbon emissions and climate change mitigation	Avoided emissions, carbon footprint
Raw material availability	PRM and SRM consumption, abiotic resource depletion
For business	**Possible indicators that can be linked to these benefits**
Cost savings	Environmental cost savings
Increased energy efficiency	Energy and exergy indicators
New partnerships	Creation of IS
Speed up innovations and invest in R&D	Innovation and investment in R&D
New patents	Innovation and investment in R&D
Additional sales and increased turnover	Revenue from creation of new products and services, revenues as a result of IS
Reduction of operation costs	OPEX indicators
Green profile, better public image	Level of social acceptance, community development
Decrease footprint	Carbon, water and ecological footprints, LCA indicators, resource efficiency indicators
Income from sale of by-products	Revenues as a result of IS
Infrastructure sharing	Creation of IS

Current report can be considered as a first step of finalization of the indicator-based assessment of the FISSAC IS model. The list of indicators proposed in this report will be further discussed especially under WP3 and WP6. Some adjustments to the list, if deemed necessary, can be made during LCA, eco-design, and ETV activities. Furthermore, during establishment of FISSAC IS model, in particular while developing the FISSAC Platform, the indicator list is expected to be revisited. As the studies on technical aspects of valorisation of SRMs under FISSAC scheme progresses, new indicators may be added or some indicators may be prioritized over others to obtain an even more tailored list of FISSAC IS indicators. In this sense, the reader is urged to consider work on IS indicators as iterative as changes may occur on the final list in the light of forthcoming project activities.

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Project funded by the European Union's
Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

ANNEX: SUPLEMENTARY INFORMATION

CHAPTER 3: EXISTING INDICATORS

Table S. 1 List of projects funded under FP7 related to SDIs

SMILE — Synergies in multi-scale inter-linkages of eco-social systems
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=SMILE&FRM=1&STP=10&SIC=SICSOC&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=88426 Website: http://www.smile-fp7.eu/ Duration: 42 months, 1.1.2008 – 30.6.2011
IN-STREAM — The Integration of Mainstream Economic Indicators with Sustainable Development Objectives
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=INSTREAM&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=88213 Website: http://www.in-stream.eu/ Duration: 36 months, 1.10.2008 – 30.9.2011
WIOD — World Input-Output Database: Construction and Applications
Cordis: http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=10745239 Website: http://www.wiod.org/ Duration: 32 months, 1.5.2009 – 30.4.2012
OPEN: EU — One planet economy network Europe
Cordis: http://cordis.europa.eu/projects/rcn/91316_en.html Website: http://www.oneplaneteconomynetwork.org/ Duration: 36 months, 1.9.2009 – 30.11.2011
TESS —Transactional Environmental Support System
Website: http://www.tess-project.eu/ Duration: ONGOING
CREEA — Compiling and Refining Environmental and Economic Accounts
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=CREEA&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=97380 Website: http://creea.eu/ Duration: 36 months, 1.4.2011 – 31.3.2014
BRAINPOOL — Binging Alternative Indicators into Policy
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=Brainpool&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=100577 Website: http://www.brainpoolproject.eu/ Duration: 30 months, 1.10.2011 – 31.3.2014
APRAISE — Assessment of Policy Interrelationships and Impacts on Sustainability in Europe
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=Apraise&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=100557 Website: http://www.apraise.org/ Duration: 36 months, 1.10.2011 – 30.9.2014
E-Frame — European Framework for Measuring Progress
Cordis: http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=EFRAME&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=101409 Website: http://www.eframeproject.eu/ Duration: 30 months, 1.1.2012 – 30.6.2014

Table S. 2 Eurostat SDIs [21]

Evaluation of changes in the socioeconomic development	Sustainable consumption and production
Real GDP per capita *	**Resource productivity** *
Economic development	**Resource use and waste**
Investment	Domestic material consumption
Disposal household income	Generation of waste excluding major mineral wastes
Household saving	Hazardous waste generation
Innovativeness, competitiveness and eco-efficiency	Recycled and composted municipal waste
Labour productivity	Atmospheric emissions
Eco-innovation	**Consumption patterns**
Research and development expenditure	Electricity consumption of households
Energy intensity	Final energy consumption
Employment	**Production patterns**
Employment	Environmental management systems
Young people neither in employment or in education or training	Organic farming
Unemployment	
Social inclusion	**Demographic changes**
People at risk of poverty or social exclusion *	**Employment rate of older workers** *
Monetary poverty and living conditions	**Demography**
Risk of poverty after social transfers	Life expectancy and healthy life years at age 65
Severe material deprivation	Population growth
Income inequalities	Total fertility rate
Access to labour market	Migration
Very low work intensity	Old-age dependency
Working poor	**Old age income adequacy**
Long-term unemployment	Income level of over 65s compared to before
Gender pay gap	**Public finance sustainability**
Education	Government debt
Early leavers from education and training	Retirement
Tertiary education	The impact of ageing public expenditure
Lifelong learning	Pension expenditure projections
Education expenditure	
Public health	**Climate change and energy theme**
Life expectancy and healthy life years *	**Greenhouse gas emissions** *
Health and health inequalities	**Primary energy consumption** *
Deaths due to chronic diseases	**Climate change**
Unmet needs for medical health care	Greenhouse gas emissions by sector
Long-standing illnesses or health problems	Global surface average temperature
Determinants of health	Greenhouse gas emissions intensity of energy consumption
Production of toxic chemicals	**Energy**
Exposure to air pollution by particulate matter	Energy dependence
Exposure to air pollution by ozone	Consumption of renewables
Annoyance by noise	Electricity generation from renewables
	Share of renewable energy in transport
Sustainable transport	**Natural resources**
Energy consumption of transport relative to GDP *	**Common bird index** *
Transport and mobility	**Biodiversity**
Modal split of freight transport	Protected areas
Volume of freight transport relative to GDP	**Fresh water resources**
Modal slit of passenger transport	Water abstraction
Volume of passenger transport relative to GDP	Water quality in rivers
Transport impacts	**Marine ecosystems**
Greenhouse gas emissions from transport	Fishing capacity
People killed in road accidents	**Land use**
Average CO_2 emissions per kilometer from new passenger cars	Artificial areas
Emissions of ozone precursors from transport	Nutrient balance on agricultural land
Emissions of particulate matter from transport	
Global partnership theme	**Good governance**
Official development assistance (ODA) *	
Globalisation trade	**Policy coherence and effectiveness**
Imports from developing countries	Citizens' confidence in EU institutions

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grant agreement Nº 642154.

Imports from least-developed countries	Infringement cases
Subsidies for EU agriculture	Transposition deficit of EU law
Financing of sustainable development	**Openness and participation**
Financing for developing countries	Voter turnout
Share of foreign direct investment in low-income countries	Citizens' online interaction with public authorities
Share of untied assistance	**Economic instruments**
Bilateral official development assistance	Environmental taxes compared with labour taxes
Global poverty	
Global resource management	
CO_2emissions per inhabitant	
Access to water	

* Headline indicators

Table S. 3 Indicators used for the 2009 EPR [13]

Indicator	DPSIR
Climate Change and Energy	
Global air temperature change	S
Concentration of CO_2in the atmosphere	P
Natural disasters linked to climate change	I
Total Kyoto greenhouse gas emissions	P
Share of energy produced from renewable energy sources in final energy consumption	R
Electricity produced from renewable energy sources	R
Combined heat and power generation	R
Energy intensity	R
Final energy consumption by transport	D
Average CO_2 emissions from passenger cars	D
Cumulative spent fuel from nuclear power plants	D
Nature and biodiversity	
Common birds	S
Conservation status of habitats by habitat group	S
Conservation status of species by taxonomic group	S
Landscape fragmentation	P
Topsoil organic carbon content	S
Freight transport	D
Area occupied by organic farm	R
Area under agri-environmental commitment	R
Natura 2000 area (% terrestrial area)	R
Environment and health	
Urban population exposure to air pollution by particles	S
Urban population exposure to air pollution by ozone	S
Transport noise in urban agglomerations	P
Emission projections for air pollutants	P
Air emissions of nitrogen oxides	P
Water exploitation index	P
Production of toxic chemicals	P
Production of environmentally harmful chemicals	P
Pesticides residues in food	P
Natural resources and waste	
Fish catches from stocks outside safe biological units	S
Total waste generated	P
Municipal waste generated	P
Recycling of packaging waste	R
Environment and economy	
Environmental taxes	R
Green jobs	R
Net electricity generating installations in EU	R
Implementation	
Infringements of EU environmental legislation	Performance indicator

D: Driving force, P: Pressure, S: State, I: Impact, R: Response

Table S. 4 EEA core indicator set [25][26]

Indicator	EEA class	DPSIR	Indicator	EEA class	DPSIR
Air pollution indicators					
Emission of acidifying substances	B	P	NO_x emissions	B	P
Emissions of ozone precursors	B	P	NH_3 emissions	B	P
Emissions of primary PM and secondary PM precursors	B	P	NMVOC emissions	B	P
Exceedance of air quality limit values in urban areas	A	S	Heavy metal emissions	B	P
Exposure of ecosystems to acidiphication, eutrophication and ozone	B	S	POP emissions	B	P
SO_2 emissions	B	P			
Biodiversity indicators					
Climate indicators					
Production and consumption of ozone depleting substances	D	D	Greenhouse gas emission trends	B	P
Progress to greenhouse gas emission targets	A	P	Global and European temperature	A	P
Atmospheric greenhouse gas concentrations	A	S	*Other indicators not specified*		
Energy indicators					
Final energy consumption by sector	A	D	Total primary energy intensity	B	R
Primary energy consumption by fuel	A	D	Renewable electricity consumption	B	R
Renewable primary energy consumption	B	R	Efficiency of conventional thermal electricity generation	C	D
Final energy consumption intensity	A	D	Share of renewable energy in final energy consumption	C	I
Overview of the European energy system	C	D	Progress on energy efficiency in EU	C	R
Overview of the electricity production and use in EU	C	D			
Water indicators					
Use of freshwater resources	A	P	Oxygen consuming substances in rivers	A	S
Nutrients in freshwater	A	S	Nutrients in transitional, coastal and marine waters	A	S
Bathing water quality	A	S	Chlorophyll in transitional, coastal and marine waters	A	S
Urban wastewater treatment	A	R	Hazardous substances in marine organisms	A	P
Emission intensity of agriculture in Europe	C	P	Emission intensity of domestic sector in Europe	C	P
Emission intensity of manufacturing industry in EU	C	P			
Waste and resources					
Waste generation		P	Waste recycling		R
Diversion of waste from landfill		R	Total primary energy intensity		R
Decoupling of resource use from environmental pressures		D	Decoupling of resource use from environmental impacts		D

D: Driving force, P: Pressure, S: State, I: Impact, R: Response

A: descriptive indicator, B: performance indicator, C: eco-efficiency indicator, D: policy effectiveness indicator, E: total welfare indicator

Table S. 5 UNEP SCP Indicators [27]

Domain	Indicators
Scale of resource use	Domestic Material Consumption (absolute and per capita)
	Material footprint (absolute and per capita)
Decoupling economic activity from resource use and environmental impact	National material efficiency – material productivity (GDP per unit material use) Production side: Material used measured through Domestic Material Consumption Consumption side: Material used measured through material footprint
	National energy efficiency – Energy productivity (GDP per unit of energy use)
Impacts	Contaminants in air, water and soil from industrial sources, agriculture, transport and water/wastewater treatment plants
	Number of persons killed or injured by a natural and technological disaster and economic losses

Project funded by the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 642154.

	Ocean health
Technology and lifestyles	Sectorial material and energy efficiency
	Market share of goods and services certified by sustainability labelling schemes
Financing and investing to transform the economy to SCP	Amount of R&D spending on environmentally sound technologies
	Amount of fossil fuel subsidies, per unit of GDP (production and consumption), and as proportion of total national expenditure on fossil fuels
Policy support for SCP	Number of countries with SCP National Action Plans or SCP mainstreamed as priority
	Number of countries with inter-ministerial coordination and multi-stakeholder mechanisms supporting SCP

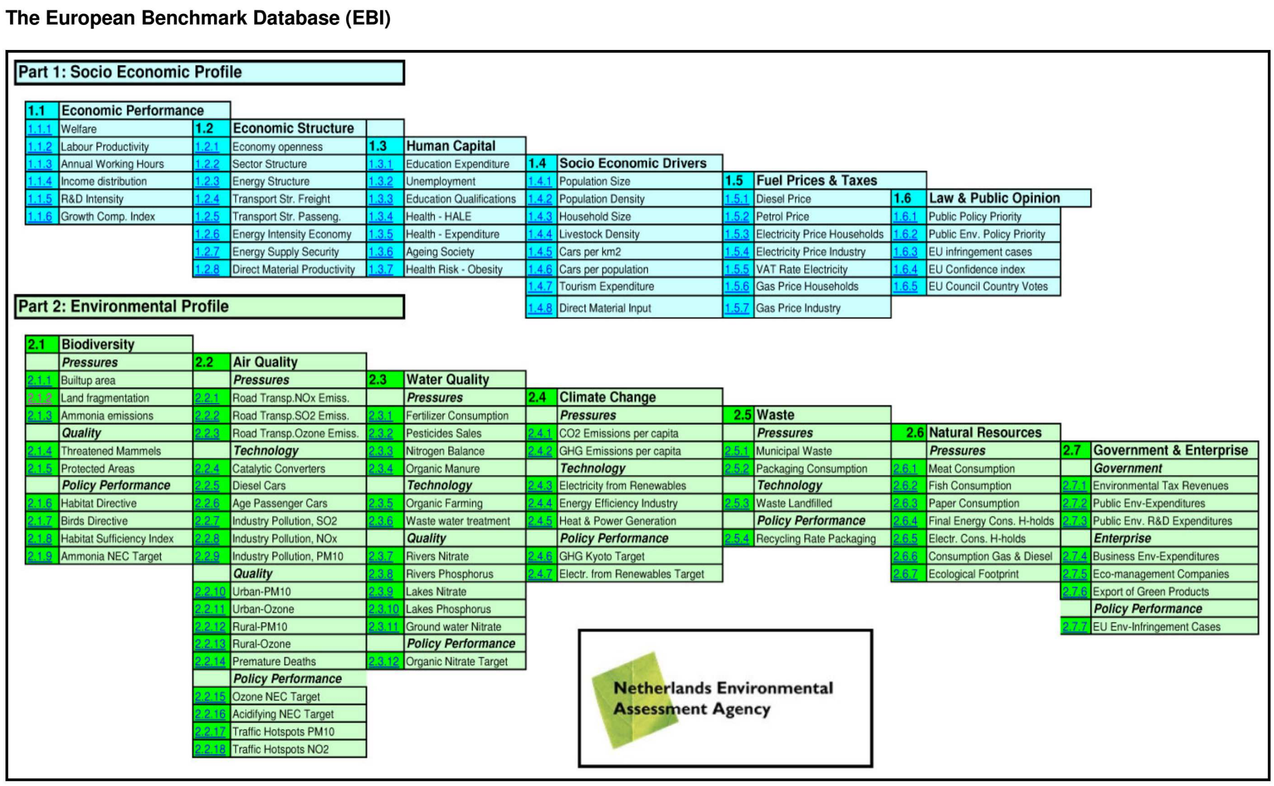

Figure S. 1 The European Benchmark Indicators [28]

Table S. 6 Relation of environmental material indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Primary Raw Materials (PRM)		
Total PRM Consumption	UNEP SCP indicators	[27]
PRM Intensity	UNEP SCP indicators	[27]
	Cement sectorial KPIs	[82][83]
	Ceramic KPIs	[84]
Increase or Decrease in Total PRM Consumption	IS indicators	[85]
	Resource efficiency indicators	[11]
Rate of PRM Substitution	Resource efficiency indicators	[11]
Secondary Raw Materials (SRM)		
SRM valorisation (substitution)	Cement sectorial KPIs	[81]
Raw Materials (RM)		
Total RM consumption	EEA Core set	[25][26]
	UNEP SCP indicators	[27]
	IS indicators	[80][86]
	Resource efficiency indicators	[11]
RM intensity	Cement sectorial KPIs	[81]
Material efficiency	EEA Core set	[25][26]
	UNEP SCP indicators	[27]
	IS indicators	[86]

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Table S. 7 Relation of environmental water indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Surface Water (SW)		
SW substitution	Resource efficiency indicators	[11]
Overall water utilization		
Total water consumption	EEA Core set	[25][26]
	IS indicators	[86]
Water intensity	Cement sectorial KPIs	[81]
	Ceramic sectorial KPIs	[84]
Increase or Decrease in Total water Consumption	IS indicators	[85]
Water efficiency	IS indicators	[86]

Table S. 8 Relation of energy indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Fuel		
Total Fuel Consumption	Resource efficiency indicators	[11]
Fuel Intensity	Cement sectorial KPIs	[81]
Fuel Efficiency	Ceramic sectorial KPIs	[84]
Thermal Energy (other than direct fuel use)		
Total Thermal Energy Consumption		
Thermal Energy Intensity	Cement sectorial KPIs	[82]
Thermal Energy Efficiency	Resource efficiency indicators	[11]
Electricity		
Total Electricity Consumption	Eurostat SDIs	[21]
Electricity Intensity	Eurostat SDIs	[21]
Renewable Energy		
Total Renewable Energy Consumption	EEA Core set	[25][26]
	EBI	[28]
Share of Renewable Energy Consumption	Eurostat SDIs	[21]
	EPR	[13]
	Cement sectorial KPIs	[82]
	Resource efficiency indicators	[11]
Total Energy		
Total Energy Consumption	EEA Core set	[25][26]
	IS indicators	[80][86]
	Resource efficiency indicators	[11]
Total Energy Intensity	Eurostat SDIs	[21]
	EPR	[13]
	EEA Core set	[25][26]
	Cement sectorial KPIs	[81][82]
	Ceramic sectorial KPIs	[84]
Increase or Decrease in Total Energy Consumption	IS indicators	[80][86]
	Resource efficiency indicators	[11]
Total Energy Efficiency	EEA Core set	[25][26]
	UNEP SCP Indicators	[27]
	EBI	[28]
	IS indicators	[86]

Table S. 9 Relation of air emission indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Greenhouse Gas (GHG) Emissions		
Total GHG Emissions	Eurostat SDIs	[21]
	EPR	[13]
	EEA Core set	[25][26]
	EBI	[28]
	Cement sectorial KPIs	[82][83]
	IS indicators	[80]
GHG Emission Intensity	Cement sectorial KPIs	[82]

Project funded by the European Union's
Horizon 2020 research and innovation programme under
grant agreement Nº 642154.

Increase or Decrease in Total GHG Emissions	IS indicators	[80]
	Resource efficiency indicators	[11]
Rate of Increase or Decrease in Total GHG Emissions	Resource efficiency indicators	[11]
Change in GHG Emission Intensity	Cement sectorial KPIs	[82]
Total Air Emissions		
Total Air Emissions	Eurostat SDIs	[21]
	EPR	[13]
	EEA Core set	[25][26]
	UNEP SCP Indicators	[27]
	EBI	[28]
	Cement sectorial KPIs	[81][83]
	Ceramic sectorial KPIs	[84]
	IS indicators	[86]
	Resource efficiency indicators	[11]
Increase or Decrease in Total Air Emissions	Resource efficiency indicators	[11]

Table S. 10 Relation of wastewater indicators to existing indicators

Indicator	Relation to existing indicator sets	Ref
Wastewater		
Wastewater Generation Intensity	Ceramic sectorial KPIs	[84]

Table S. 11 Relation of solid waste indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Solid Wastes		
Total Solid Waste Generation	Eurostat SDIs	[21]
	EPR	[13]
	EEA Core set	[25][26]
	Cement sectorial KPIs	[81]
	Ceramic sectorial KPIs	[84]
Solid Waste Recycling	EEA Core set	[25][26]
Rate of Solid Waste Recycling	Resource efficiency indicators	[11]

Table S. 12 Relation of OPEX indicators with existing indicators

Indicator	Relation to existing indicator sets	Ref
Material Cost		
Total Material Cost	Cement sectorial KPIs	[81]
Increase or Decrease in Total Material Cost	IS indicators	[85][87]
Water Cost		
Increase or Decrease in Total Water Cost	IS indicators	[85]
Man-power Cost		
Total Man-power Cost	Cement sectorial KPIs	[81]
Total Operational Cost (OPEX)		
Increase or Decrease in Total Operational Cost	IS indicators	[85]

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Horizon 2020 research and innovation programme under
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