Report on Industrial Segmentation, criteria and correlation to the FISSAC first application

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D7.2: Report on Industrial Segmentation, criteria and correlation to the FISSAC first application
WP 7, T 7.3

Author: RINA-C

H2020-WASTE-2014-two-stage

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Technical References

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<tr>
<th>Project Acronym</th>
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<td>Project Title</td>
<td>FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN</td>
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<td>RINA-C</td>
<td>Barbieri C., Merello L., Rocco E., Strazza C., Vela S.</td>
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1 PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)
0. SUMMARY

The main objective of WP7 “Industrial Symbiosis replicability and social issues” – with specific reference to Task 7.3 - is to demonstrate the replicability of FISSAC model. The assessment developed for this purpose covers the issue of replicability from the following perspectives:

- the replicability of the industrial symbiosis opportunities investigated within the project;
- the replicability of the model to different fields and type of products;
- the replicability of the model in different EU target countries.

Indeed, the ambition of the FISSAC model is its replication in other regions different from the ones of FISSAC project (Belgium, Czech Republic, Germany, Hungary, Italy, Spain, Sweden, Turkey and UK) and other value chains symbiosis scenarios different from the construction one.

In this approach, industrial symbiosis is interpreted as a strategy to achieve circular economy transition, therefore instruments and methodologies proposed are mainly derived from circular economy field, but are then tailored for the application with respect to the specific topic of industrial symbiosis.

Within D7.2, “Report on Industrial Segmentation, Criteria and correlation to the FISSAC first application”, the replicability concept is thus investigated in order to set up a methodology for industrial segmentation and for evaluation or replicability potential, through a list of tailored criteria to guide the assessment of different opportunities.

When dealing with replicability, all cases having more proximity with the FISSAC scenario are potentially the ones having a higher replicability potential. For this reason, in order to identify new possible sectors with industrial symbiosis potential, it has been decided to segment the industrial sectors in a sequential way, starting from the ones having more proximity with the FISSAC ones, up to other streams across the extended construction value chain and application sectors.

As examples, some sectors that are currently subject of interest in the field of industrial symbiosis and circular economy are particularly investigated. The main goal of the overview is indeed to give a general idea about the technological feasibility of industrial symbiosis scheme within the selected sector, without posing any specific assumption about the level of implementation foreseen and the system boundaries. When aiming at completing the replicability assessment for the sectors, having established boundary conditions with a sufficient level of detail, critical parameters of material streams, non-technical barriers, economic, environmental and social impacts and, finally, about the options to integrate all the information within an ICT tool shall be carried out.

On this basis, the developed methodology aims to provide some instruments to evaluate the replicability potential of the FISSAC model, as high-level assessment. Specifically, two different approaches are proposed: qualitative and quantitative.

The qualitative methodology is based on a list of criteria that can guide a high-level evaluation of the replicability thanks to the definition of two sets of criteria, one addressing the replicability in other sectors and the other one addressing the potential for replicability in other countries. The criteria identified are aimed at investigating aspects of different nature, to cover all the possible opportunities and weaknesses for the scheme under analysis and to enable to identify main barriers and drivers for the implementation of such symbiosis. Such kind of qualitative approach can pave the way to a synthetic representation through SWOT analysis, complementing the evaluation by illustrating strengths, weaknesses, opportunities and threats for the replicability of the FISSAC model within a certain sector in a certain country.

In order to create a solid framework for the assessment of replicability potential, the qualitative criteria are coupled with a quantitative methodology. The methodology proposed is intended to be applied in parallel with the qualitative assessment. Indeed, for a successful replication of the FISSAC model it is fundamental that both the results of the qualitative analysis and of the quantitative analysis are positive, as the two approaches are complementary. For the development of the methodology, acknowledging that reliable and robust information on materials stocks and flows is considered among the prerequisites for a deeper understanding and a better monitoring of the effectiveness of different industrial strategies and for the promotion of innovation. The need of identifying and quantifying material stocks and flows within a fixed boundary (e.g. Europe, industrial park, etc.) is thus a fundamental concept of the
quantitative methodology. The methodology is built on the pillars of Material Flow Analysis (MFA), which can be defined as a “systematic assessment of the flows and the stocks of materials within a system defined in space and time”. It consists in a quantitative analysis of mass flows within a system, based on the principle of mass conservation and it is applied in various industrial areas in order to control pathways for material use and industrial processes, to create loop-closing industrial practices to balance industrial input and output to natural ecosystem capacity. Within the tailored methodology, MFA principles and concepts can be easily implemented and visualized through a Sankey diagram of material flows. Considering the final aim of defining a methodology for assessing replication potential, a set of indicators is extrapolated from the Sankey diagram representation. As a final step, aiming at addressing more in depth and from a holistic perspective - the issues of replicability for the value chains studied within the FISSAC project at EU level, the quantitative methodology introduced is expanded, focusing on the evaluation of economic and environmental benefits of replicating industrial symbiosis for FISSAC value chains.

As a direct follow-up of the activities described and reported in this deliverable, within D7.5, “Project Validation, SWOT and Concept replicability”, the here defined criteria and protocol will be applied in order to assess in detail the replication potential in other geographical and sectoral contexts.
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Abbreviations and acronyms

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<tr>
<td>CDM</td>
<td>Construction and demolition materials</td>
</tr>
<tr>
<td>CDW</td>
<td>Construction and demolition wastes</td>
</tr>
<tr>
<td>CE</td>
<td>Circular Economy</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>IS</td>
<td>Industrial Symbiosis</td>
</tr>
<tr>
<td>JRC</td>
<td>Joint Research Center</td>
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<tr>
<td>WPC</td>
<td>Wood-rubber-plastic composites</td>
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1. INTRODUCTION

1.1 Circular economy and industrial symbiosis

Industrial symbiosis is a form of brokering to bring companies together in innovative collaborations, finding ways to use the waste from one as raw materials for another. The word “symbiosis” is usually associated with relationships in nature, where two or more species exchange materials, energy, or information in a mutually beneficial manner.

Local or wider co-operation in industrial symbiosis can reduce the need for virgin raw material and waste disposal, thereby closing the material loop – a fundamental feature of the circular economy and a driver for green growth and eco-innovative solutions. It can also reduce emissions and energy use and create new revenue streams.

Currently, Europe has some EU support networks for industrial symbiosis and European Innovation Partnerships such as National Programmes (e.g. NISP (UK)), regional initiatives (e.g.: Cleantech Östergötland (Sweden)) and Local initiatives (e.g. Kalundborg in Denmark).

However, in order to make industrial symbiosis a wide-spread commercial reality, more needs to be done to manage the flow of waste material from different sectors and industries, and there is still much to understand about:

- Environmental and societal impacts;
- Harmonization of technologies, processes, policies;
- Civil society engagement to a circular economy at EU level;
- Waste resources information;
- Waste treatment technologies;
- Business models and coordination between value chain actors.

The linear ‘take, make, dispose’ economic model relies on large quantities of cheap, easily accessible materials and energy and is reaching its physical limits. The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption. It enables key policy objectives such as generating economic growth, creating jobs, and reducing environmental impacts, including carbon emissions.

A favourable alignment of factors makes the transition possible. Resource-related challenges to businesses and economies are mounting. An unprecedented favourable alignment of technological and social factors enables the transition to the circular economy.

Industrial symbiosis, understood as strategy to achieve a circular economy transition, is the use by one company or sector of by-products, including energy, water, logistics and materials, from another. The precondition for an industrial symbiosis complex is cooperation among the companies, and these companies form a network as a result of that cooperation. Indeed, industrial symbiosis is increasingly being seen as a means to realize a circular economy and as a strategic tool for economic development, green growth, innovation and resource efficiency at all levels in Europe – local, regional, national and international.

For this reason, this report introduces instruments and methodologies mainly derived from circular economy field, but focuses with their application with respect to the specific topic of industrial symbiosis. Industrial symbiosis can be achieved from three main perspectives: characterization of the conditions under which industrial symbiosis complexes form, the exchange relationships that sustain their development, and the benefits that accrue to industries that participate in them.

1.2 WP7: Industrial symbiosis replicability and social issues

The main objective of WP7 “Industrial Symbiosis replicability and social issues” is to demonstrate the replicability of FISSAC model. In particular, technical and non-technical aspects that could affect an Industrial Symbiosis are analysed in this WP and the necessary steps to change from linear to circular business models are defined for the most representatives EC countries and FISSAC related industries. For this purpose, several concepts and instruments are applied such as Living Labs (LLs), interviews and Technological Innovation System (TIS) analysis. The WP7 activities are divided in three main tasks, whose objectives are shown in the following figure.
1.3 Task 7.3: Evaluation of the replicability of the model

In the framework of WP7, the main aim of Task 7.3 is to assess the replicability of FISSAC Model. This kind of assessment includes:
- the replicability of the IS opportunity investigated within the project
- the replicability of the model to different fields and type of products
- the replicability of the model in different EU target countries

The results of the activities of this task will be reported in two different deliverables, D7.2 and D7.5, as reported in Figure 2.

Within D7.2, “Report on Industrial Segmentation, Criteria and correlation to the FISSAC first application”, the replicability concept is presented, together with a methodology and a list of different criteria to guide the evaluation of the replicability potential – some examples of sectors for which the FISSAC model could be replicated are also provided.

Within D7.5, “Project Validation, SWOT and Concept replicability”, SWOT analysis related to the sectors and the case studies addressed by the project will be presented, as well as an assessment of the economic and environmental benefits that could be achieved at global level, when replicating IS opportunity investigated within the project in other contexts.

1.4 FISSAC project: FISSAC model, methodology and software platform tool

The FISSAC project aims to accelerate the transition to a circular economy. The FISSAC project involves stakeholders at all levels of the construction and demolition value chain to develop a methodology and software platform, to facilitate information exchanges that can support industrial symbiosis networks and replicate pilot schemes at local and regional levels.
The overall objective of FISSAC Project is to develop and demonstrate a **new paradigm built** on an innovative industrial symbiosis model towards a zero-waste approach in the resource intensive industries of the construction value chain, tackling harmonized technological and non-technological requirements, leading to material closed-loop processes and moving to a circular economy.

The new model developed within the FISSAC project has been co-developed with different stakeholders within the project framework, on the basis of the project activities and experiences made and based on the feedback of industries and relevant stakeholders - external to the project that have been engaged through different instruments such as the Living Labs. This process is not completed yet, but a First outline of FISSAC Industrial Symbiosis Model and Methodology has been presented within WP1, at M18, summarizing the main outcomes during the first months of the project. The idea is that the methodology will be presented as a procedure to implement FISSAC model, on the basis of the case studies that have been studied and demonstrated in the construction value chain scenario. The new model, supported by a methodology and a Software Platform tool is developed in order to implement the innovative industrial symbiosis model in a feasible scenario of industrial symbiosis synergies between industries (steel, aluminum, natural stone, chemical, demolition and construction sectors) and stakeholders in the extended construction value chain.

In general, FISSAC Project demonstrates the applicability of the new industrial symbiosis model as well as the effectiveness of the innovative processes, services and products at different levels, such as:

- **Manufacturing processes**, demonstrating closed loop recycling processes to transform waste into valuable acceptable secondary raw materials and manufacturing processes for novel construction products at industrial scale
- **Product validation**, demonstrating the eco-design of eco-innovative construction products (new Eco-Cement and Green Concrete, innovative ceramic tiles and Rubber Wood Plastic Composites) in pre-industrial processes and at real scale
- **FISSAC model**, demonstrating the software platform and analyzing the replicability of the model through living lab concept (as a user-centered, open-innovation ecosystem, often operating in a territorial context).
2. FISSAC MODEL REPLICABILITY

The ambition of the FISSAC model is its replication in other regions different from the ones of FISSAC project (Belgium, Czech Republic, Germany, Hungary, Italy, Spain, Sweden, Turkey and UK) and other value chains symbiosis scenarios different from the construction one. As for case studies, the project activities address some specific sectors, materials and products, with special focus on the countries object of the demonstration; however, the same approach can be replicated, following the same pattern, across the extended construction value chain.

The aim of this task is to provide instruments to assess the potential of the replicability of the FISSAC model. The concept of replication is here intended in different perspectives:

- replicability of the industrial symbiosis opportunities investigated within the project;
- replicability of the model to different fields and type of products;
- replicability of the model in different EU target countries.

The first perspective is the one having more proximity with the activities performed within the project: the synergies analyzed within the project could be replicated in very similar contexts – same materials and sectors involved, same regions. This should ensure high replicability, since the lesson learnt within the project can be directly applied to other cases.

With reference to the other two situations, the ambition is to start from the demonstrated industrial symbiosis opportunities and replicate something similar in other contexts, which could be different sectors, involving different materials, or different countries, which could present slight differences if compared to the ones involved in the project. The subdivision of the assessment in these two parallel evaluations is based on the idea that through the assessment of replicability in other value chains the general feasibility of the replication is investigated, while through the assessment of replicability in other EU countries the boundary conditions for the replication of the model are taken into account. This approach enables to break up the complex problem of replicability assessment into two main components, one tailored on a framework scale, and one tailored on a national scale. In general, the more the evaluated case is far from the FISSAC ones, the more the model could require some adjustment to be applied, on the basis of the specific requirement.

The assessment of replicability is the key to understand whether a form of industrial symbiosis, with related business model, may be consistently and reliably duplicated in other sectors or in other countries. Thus, a replicable model is able to serve the greatest number of customers, while remaining cost-effective.

Replicability is, in general, affected by a large number of factors, such as sector-specific features, geographic location, market conditions, policy and legal framework and its enforcement, social and stakeholder interactions, technological development, level of information and awareness, available skills, etc. Due to the complexity of the issues influencing replicability, simplified models and schemes can be referred to carry out a preliminary qualitative assessment. In subsequent steps, qualitative analyses may be enlarged and enriched with quantitative evaluations on the most relevant aspects.

2.1 Tools for replicability

Stakeholder interested in replicating the same model followed within the project can be guided and facilitated by the developed methodology to overcome technical barriers (transformations and adaptations of industrial and recycling processes) and non-technical barriers (social and cultural, legislative/regulatory, economic, organizational) as well as standardization concerns to implement and replicate industrial symbiosis in a local/regional dimension.

Among the objectives of the FISSAC projects, some are sector and materials specific (manufacturing processes and product validation) so they can be replicated in analogous contexts or taken as an example to replicate the same pathway in other contexts; other are more horizontal, and potentially applicable to all contexts: not only to the cases evaluated within the project, but also applicable to other sectors, products or in other countries. Indeed the FISSAC model includes the software platform and the living lab concept that are tools that can be easily used in different contexts and are considered as valid instruments to facilitate the replicability process – they are presented in the following sub-chapters.
2.1.1 FISSAC ICT Platform

FISSAC ICT Platform is a web-based tool that aims to facilitate the industrial symbiosis establishment. One of the objective of the Platform is to engage different stakeholders and to provide information related to industrial symbiosis opportunities. For engaging and attracting users, the platform presents information about FISSAC project and its results, IS success stories as well as IS best practices and benefits. The registered users can use the Platform for searching IS opportunities, providing basic facility data. Based on these data (reference process, input and output flows), the Platform provides a list of possible IS opportunities, including a short description and some information to guide their implementation. Moreover, the platform allows users to search, on the marketplace, for georeferenced facilities with which establishing the identified IS opportunities as well as to contact them for the implementation through a messages tool.

In addition, through the Platform it is possible to design a facility in a more detailed way, specifying the raw materials usages, waste materials, products of that facility – this allows to make extended analysis and comparisons. Indeed with the support of an expert, after designing is complete, it is possible to search through the facility databases to find the best possible facility or facility groups to form a network. Experts can compare networks and facilities based on indicators, LCA, cost analysis.

Performance evaluation part allows facilities, experts to make the desired comparisons and evaluations before and after IS network are formed. After a network is formed, performance evaluation system auto sends default charts and graphs based on facility relations. In addition, experts can write reports based on the networks they are working on through messaging and reporting tool.

The utilization of the FISSAC ITC Tool can facilitate stakeholders that are interested in establishing IS initiative in different ways, summarized in Figure 3 below.

Figure 3 - FISSAC tool website, http://platform.fissacproject.eu/.

Interested users can find the necessary information for the utilization of the FISSAC ITC tool in the D6.4, “FISSAC Platform Final Version” and on the tool website.

It is worth noticing that the Platform version developed within the project is specially focused on the construction value chain and on the sectors and IS opportunities investigated by the FISSAC project. However, the Platform has the potential to be extended to other sectors and to different stakeholders. In particular, this will be possible thanks to the Symbiosis Expert, who has the competencies to identify and validate new opportunities and can make them available for a small network that he/she is associated with or for the entire users, defined as follows:

**Symbiosis Experts are literally the “Officers of the Platform”. A Symbiosis Expert should be highly experienced on IS processes. In other words, Symbiosis Experts are involved in every step of IS process. Some of the important tasks of Symbiosis Experts are facility engagement, data gathering, opportunity assessments, monitoring, performance assessments and general management tasks. Symbiosis experts are responsible of the internal communication of roles and tasks to improve industrial symbiosis phases. Symbiosis Experts are responsible with the data input tasks and its validity. Symbiosis Expert role is also responsible of the communication between system designers and facilities to improve the accuracy and reliability of modelling phase. This role is also responsible of dealing opportunity matching and offers.**
2.1.2 Living Labs

Living Lab (LL) is a user-centric platform that is based on every day practices and experiences and research. It facilitates user influence in an open and collaborative innovation process engaging all pertinent stakeholders in real life context, aiming to create validated and sustainable values and often operating in a territorial context.

Within the FISSAC Project, nine LLs are set up in UK, Germany, Sweden, Czech Republic, Hungary, Turkey, Belgium, Spain and Italy. LLs aim to exploit knowledge about technological and non-technological factors that could impact Industrial Symbiosis (investigating different value chains, countries and stakeholders, etc.) and to co-develop with LLs participants the FISSAC Model, based on circular economy, with a special focus on developed eco-innovative products. The Living Labs should reflect the priorities of stakeholders in the different countries; investigate relevant aspects of the FISSAC model; and bring valuable inputs to solve problems and explore pathways within the project and in some cases beyond.

Since the need to know each other and trust among stakeholders are recognized as important conditions for the instauration of industrial symbiosis, the development of Living Lab is considered a good instrument to be applied by stakeholders interested in investigating Industrial symbiosis. The same approach followed within the FISSAC project by the LL responsible partners can be easily replicated in other contexts but also in different sectors or countries, to investigate the possibility to establish synergies among facilities, to share experiences and best practices, to find solutions for encountered obstacles.

The guidelines as well the examples of organized LL contained in D7.1, “First publications regarding Living Lab for FISSAC model” can be used as a guide for replicating the same approach.

On the FISSAC website (Figure 4), it is possible to find different information on the organized Living Labs, as well as their main outcomes.

Figure 4 – Living Lab page on FISSAC website

3. INDUSTRIAL SEGMENTATION

In the project case studies framework, different industries are investigated to analyze their industrial symbiosis potential: steel, aluminum, natural stone, chemical and demolition and construction sectors. The FISSAC scenario is reported in Figure 5.

Figure 5 - FISSAC scenario

When dealing with replicability, all cases having more proximity with the FISSAC scenario are potentially the ones having a higher replicability potential: this is why, within the project, all the barriers encountered are analyzed and different solutions are proposed. For this reason, in order to identify new possible sectors with IS potential across the extended construction value chain, it has been decided to segment the industrial sectors in a sequential way, starting from the ones having more proximity with the FISSAC ones, as schematically illustrated in Figure 6 below.

Figure 6 - Replicability potential

Dealing with the same kind of waste streams or with the same kind of products facilitate the model replicability, providing at the same time good instruments for barriers removal. Basically, starting from the FISSAC scenario, it is possible to enlarge the scenario, answering to the following questions:

- Is it possible to use the same waste stream for another application?
- Is it possible to use another waste stream for the same application?

Progressively enlarging the scenario can lead to the evaluation of completely new opportunities, dealing with new waste streams, new products and new sectors.

This approach for industrial segmentation, starting from the FISSAC scenario, is schematically depicted in Figure 7.
An example about how this approach could be applied is reported in Figure 8. Each “X” corresponds to an IS opportunity, whose potential can be further investigated.
3.1 Examples of sectors - Insights

This section includes a selection of examples of sectors that can show – at a very preliminary level - a certain potential for replicability of the FISSAC model, on the basis of the principles of industrial segmentation.

In particular, the attention has also been expanded to some sectors that are currently subject of interest in the field of industrial symbiosis and circular economy, therefore they not represent the selection of the most significant candidates for replication, but they have been investigated as example in order to provide useful insights to successively define some of the replicability criteria in the developed methodology.

Specifically, for each segment a general overview of the sector is presented, with a close eye on information useful for some parameters for the assessment of replicability potential in different value chains, namely: previous industrial symbiosis experiences in the sector, existence of previous and current IS initiatives at European and international level, for the specific waste material stream, specific regulation on waste management, existence of technological processes able to transform waste into secondary raw materials. These aspects have been taken into account as they are representative of the replicability potential despite the specific geographic boundaries and the extent of the symbiosis of a specific case study. The main goal of the overview is indeed to give a general idea about the technological feasibility of industrial symbiosis scheme within the selected sector, without posing any specific assumption about the level of implementation foreseen and the system boundaries. In addition, for each sector, a description of pertinent NACE codes is proposed, in order to guide the research of data through the Eurostat database.

When aiming at completing the replicability assessment for the sectors, having established boundary conditions with a sufficient level of detail, critic parameters of material streams, non-technical barriers, economic, environmental and social impacts and, finally, about the options to integrate all the information within an ICT tool shall be carried out.

In Table 11 the main findings of the analysis performed are summarized.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Main upstream flows</th>
<th>Core processes and flows</th>
<th>Main downstream flows</th>
<th>Current level of sustainability</th>
<th>Novel sustainable practices</th>
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<tr>
<td>BRICK</td>
<td>Clay</td>
<td>Forming, drying, firing and cooling</td>
<td>N/A</td>
<td>Reduction of energy demand of the manufacturing process, recovery of bricks at end of life (mostly backfilling)</td>
<td>Use of secondary raw materials (glass cullet) or by-products (fly ash) to substitute clay and recycle and reuse at end of life</td>
</tr>
<tr>
<td>WEEE</td>
<td>N/A</td>
<td>Metals (including critical raw materials), plastics and glass</td>
<td>N/A</td>
<td>Low levels of collection and high recovery rates are registered in Europe. Treatment centers separate the most valuable components.</td>
<td>Improvement of technologies to increase recycle rates of critical raw materials. Plastic incineration for syngas or chemicals production. Use of recycled glass for manufacturing of packaging, insulation, window, sandblasting material. Use of leaded glass as silica slagging agent or as chemical in pyrometallurgical processes</td>
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Table 11 - Main findings

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3 [https://ec.europa.eu/eurostat/data/database](https://ec.europa.eu/eurostat/data/database)
### Sector

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<tbody>
<tr>
<td>PAPER</td>
<td>Pulp, Paper for recycling</td>
<td>Pulping, Blending, Refining, Screening, Cleaning, Papermaking</td>
<td>Paper sludge</td>
<td>High level of paper for recycling rate (i.e. the percentage of paper for recycling utilization compared to the total paper production)</td>
<td>Possibility to use paper sludge for different applications (e.g. in the cement and brick industry, to improve porosity)</td>
</tr>
<tr>
<td>COPPER</td>
<td>Ore, Scrap (secondary material)</td>
<td>Mining and processing, Smelting, Converting, Fire refining, Electrolytic refining</td>
<td>Copper slag; Precious metals</td>
<td>Scrap copper covers around 50% of EU demand for copper. Recycling copper requires 85% less energy than primary production.</td>
<td>Use of copper slag as secondary raw material in various value added products</td>
</tr>
</tbody>
</table>

### BRICK SECTOR

The EU ceramics industry, manufacturing products such as tiles, bricks, sanitary ware, or vitreous clay pipes is mainly composed by innovative small and medium-sized enterprises. Most manufacturers are innovative small and medium-sized enterprises. NACE Rev. 2 codes covering activities relevant for the brick industry are illustrated in Table 12 below.

### Table 12 - NACE codes for the brick manufacturing sector

<table>
<thead>
<tr>
<th>NACE Rev. 2 codes for the brick manufacturing sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.3 Manufacture of clay building materials</td>
</tr>
<tr>
<td>23.31 Manufacture of ceramic tiles and flags</td>
</tr>
<tr>
<td>23.32 Manufacture of bricks, tiles and construction products, in baked clay</td>
</tr>
</tbody>
</table>

Figure 9 shows the main processes of traditional brick manufacturing industry. Essentially, bricks are produced by mixing ground clay with water, forming the clay into the desired shape, and drying and firing. Clay, the main raw material used for bricks manufacturing, is an abundant natural raw material. For brick manufacturing purposes, clay must possess some specific properties and characteristics. Such clays must have plasticity, which permits them to be shaped or modelled when mixed with water; they must have sufficient wet and air-dried strength to maintain their shape after forming. Also, when subjected to appropriate temperatures, the clay particles must fuse together [1].
Specifically, the manufacturing process presents several general phases, namely:

- mining and storage of raw materials: mining generally takes place in open pit mines, and storage allows to have a continuous production even when wheatear conditions do not allow excavation;
- preparing raw materials, in order to reduce the size of raw material before mixing operations;
- forming the brick, including the operations associated to a homogeneous plastic clay mass;
- drying, firing and cooling, which are, respectively, the processes through which most of the water is evaporated from the wet bricks, bricks are loaded and fired in kilns and then are cooled;
- de-hacking and storing finished products.

Within the ceramics industry, the brick sector stands as a crucial sector when dealing with sustainability issues. Indeed, the brick manufacturing process is among the most energy intensive processes within the ceramic sector and down-cycling into material for road construction or landfilling are not rare practices for the end-of-life management.

For the aforementioned reasons, and for the significant amount of brick mass flows either produced or dismantled every year in Western Countries, novel solutions for a more efficient performance, from a sustainability perspective, of the entire bricks value chain are being explored since recent years. These sustainability initiatives are often focused on the reduction of energy consumption for the manufacturing process rather than on reduction of demand for primary raw material, as clay is abundantly available in nature.

When dealing with sustainable and circular practices in the upstream flows, in literature, opportunities such as using processed glass cullet or fly ash during brick manufacturing process, are explored [2], [3]. In detail, glass cullet can be used as fluxing agent, i.e. as a material that lowers the vitrification temperature of ceramics in order to reduce energy demand for firing process. On the other hand, fly ashes can be used for the manufacturing of fly ash clay bricks in addition to a clay component. Fly ash is a byproduct of coal burning from thermal power stations, and can be used to reduce the need for virgin material. Furthermore, within the H2020 HISER project, new cost-effective bricks manufactured with a partial replacement (up to 10% by weight) of inert sand fraction by C&D recovered ceramic material are considered as a case study.

In order to give an idea about current level of implementation of such practices in Europe, it can be considered that currently, in UK, which accounts for most of the brick production within Europe, an average of 9% of materials used in the manufacture of clay bricks consists in materials derives from alternative resources, recycled and secondary raw materials.

If downstream flows are considered, the fact that the volume of such waste per tonne of bricks manufactured is very low should be taken into account. Typical ‘wastes’ associated with brick production can include fired brick waste, paper, wood, cardboard, plastic, refractories, abatement plant residue, as well as obsolete plant and machinery.

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5 http://www.hiserproject.eu/
Wherever possible, these materials are re-used or recycled, for example, by crushing and re-using the waste again in the same process, or as raw material for other products [4]. In addition, at their end-of-life, bricks are sometimes recovered through close loop recycling or reuse or down-cycled into backfilling materials. Another available opportunity is to use recycled clay bricks as an aggregate for concrete mixtures production, being cheaper and more sustainable than the conventionally used cement binder. By using recycled clay brick as an aggregate for concrete production, it is indeed possible to design concrete mixtures in the same way as the design mixtures for commonly used aggregates [5].

**WEEE SECTOR**

Electrical and Electronic Equipment (EEE) is defined as equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields.

Considering the complexity and variety of EEE products and material streams involved within the EEE sector, this example focuses solely on the description of the state of art and of main sustainability practices in the management of waste generated from electrical and electronic equipment (WEEE).

Main NACE Rev. 2 codes covering activities relevant for the EEE and WEEE industry are illustrated in Table 13 below. Furthermore, Eurostat database reports several data available for consultation dedicated specifically to EEE production and WEEE management.

Table 13 - NACE codes for the EEE and WEEE sector

<table>
<thead>
<tr>
<th>NACE Rev. 2 codes for the EEE and WEEE sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
</tr>
<tr>
<td>26.1</td>
</tr>
<tr>
<td>26.2</td>
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<tr>
<td>26.3</td>
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<td>26.4</td>
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<td>26.5</td>
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<td>26.6</td>
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<td>26.7</td>
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<td>26.8</td>
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<tr>
<td>27</td>
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<tr>
<td>27.1</td>
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<td>27.2</td>
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<tr>
<td>27.3</td>
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<tr>
<td>27.4</td>
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<tr>
<td>27.5</td>
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<tr>
<td>27.9</td>
</tr>
<tr>
<td>29</td>
</tr>
<tr>
<td>29.31</td>
</tr>
</tbody>
</table>

WEEE is currently considered to be one of the fastest growing waste streams in the EU, growing at 3-5 % per year. It contains diverse substances that pose considerable environmental and health risks if treated inadequately. On the other hand, the recycling of WEEE offers substantial opportunities in terms of making secondary raw materials available on the market⁶. Around 3.8 tonnes of WEEE containing valuable raw materials such as metals and plastics are collected each year in the EU, with levels of collection and recovery that vary from country to country (raw material scoreboard) and, considering current market size, it is likely that WEEE is a flow with high market potential for IS [6].

Despite being a small waste stream in mass, especially when compared to streams such as construction and demolition waste, its treatment is important as it is a source of valuable and critical raw materials (i.e. materials that have a high risk of supply shortage in the next 10 years and with high economic relevance) that can be recycled.

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Across European MSs, collection of WEEE is only in the order of 38%, with respect to the overall amount of EEE produced. Collected WEEE are generally recycled with high efficiency in terms of mass. These high rates result from the recycling of base materials (e.g. ferrous metals, aluminum, copper), while material losses are often associated to plastics that are not prepared for reuse and recovery or special metals [7]. On the other hand, non-separated WEEE ends up with the ordinary municipal waste and is incinerated for the purpose of energy recovery or disposed. Figure 10 shows the main phases of electric and electronic equipment life-cycle. It is highlighted, that in the case of industrial symbiosis practices, the production of new products from waste may lead to the generation of goods that are not EEE, but belong to other value chains.

Figure 10 - EEE lifecycle diagram [29]

WEEE management is regulated under the WEEE Directive⁷, but it also falls under the legislation restricting the use of hazardous substances in the electric and electronic equipment. In Europe, Large amounts of WEEE are improperly or illegally collected and treated, and overall the level of collection is well below the amount of EEE entering the market. This situation represents an opportunity to encourage industrial symbiosis practices for this flow.

Common treatment for WEEE consists in various steps, including dismantling and decontamination, shredding into small pieces, magnetic separation of ferrous content, optical sorting for the collection of electronic cards, containing critical raw materials, separation of non-ferrous material by Eddy currents, separation of the plastics by optical sorting or floating [8] and separation of glass for example through the “hot wire” method [9].

Below, the main materials composing common WEEE and their specific recovery routes are described:

- **Metal**: metal separation is commonly carried out with traditional technologies, even though in order to reach high levels of separation, taking into account the chemical and physical features of each metal, qualified personnel for surveillance is to be engaged. Scrap metals extracted may re-enter into metal industries. For high value metals, recovering processes are being studied given the relevant economic value of metals such as gold, silver, platinum, that are commonly contained into electronic cards;

- **Plastic**: plastic represents a large portion of the volume of treated waste, even though it is often the case that it is not designed and conceived to be reused and recycled. Recovery routes for plastic other that closed loop

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recycling and reuse include the possibility of introducing plastic from WEEE in the plastic industry, via chemical recycling in form of pyrolysis or breakdown to monomer. Other possible routes, which are being currently explored are the incineration for syngas production and chemicals recovery for the chemical industry sector. The only limitation to plastic recovery, is the possibility of contamination from hazardous substances;

- Glass: glass represents approximately 5% w/w of WEEE composition. After being depurated from the presence of hazardous materials, glass can be recycled either remaining in the EEE sector or into products addressed to other sector. Some examples with respect to this second case are: use of glass crushed and despatched as cullet in the container manufacturing, use of glass for manufacturing glass wool to be used as insulation, glass bottles and packages, window glass, and sandblasting material, use of leaded glass from TVs – not usable in the production of more modern LCD TVs as a silica slagging agent in lead smelters or into other pyrometallurgical processes.

**PAPER SECTOR**

The pulp and paper industry, which is covered under codes given in Table below according to NACE Rev2, supplies an essential product – paper – to over 5 billion people worldwide; the total production of paper and board in Europe in 2018 reached 92.2 million tonnes [10].

**Table 14 - NACE codes for paper industry**

<table>
<thead>
<tr>
<th>NACE Rev. 2 codes for the paper industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
</tr>
<tr>
<td>17.1</td>
</tr>
<tr>
<td>17.11</td>
</tr>
<tr>
<td>17.12</td>
</tr>
<tr>
<td>17.2</td>
</tr>
</tbody>
</table>

Even if at the beginning papermaking was a slow and labour-intensive process, nowadays pulping and papermaking are driven by advanced technical equipment and high-speed paper machines able to produce rolls of paper at a speed up to 2 000 m/min. Figure below shows an overview of the pulping and papermaking process.

**Figure 11 – Papermaking process – main process steps [11]**
The main ingredient for papermaking is the pulp which is produced from virgin fibre by chemical or mechanical means or by the repulping of paper for recycling (RCF). In Europe, wood is the main source of fiber, but in a few cases straw, hemp, grass, cotton and other cellulose-bearing material can be used.

In the traditional papermaking process, wood logs are first debarked and chipped into small pieces. Water and heat are added, and by mechanical or chemical means, the wood is separated into individual fibres to obtain the pulp (pulping). After screening, cleaning and sometimes refining, the fibres are mixed with water and the resulting pulp slurry is sprayed onto a flat wire screen moving at high speed through the paper machine. This movement allows water to drain out and at the same time ensure the bonding of the fibres together. The web of paper is pressed between rolls which squeeze out the residual water and press it to make a smooth surface. Heated cylinders then dry the paper, and the paper is slit into smaller rolls, and sometimes into sheets. The processes used to produce pulp and to dry paper are the major energy consumers in the industry. Indeed the energy required for paper production is comparable to that of other energy-intensive products, such as cement or steel. 

The papermaking process has the potential to become a circle when recovered paper is used, in substitution of the natural wood fiber. Recovered fibre has become an indispensable raw material for the paper manufacturing industry, because of the favourable price of recovered fibres in comparison to the corresponding grades of market pulp and because of the promotion of waste paper recycling by many European countries. According to the statistics of CEPI, the Confederation of European Paper Industries, in 2017 in Europe the average utilisation rate of paper for recycling was around 52.4 % (i.e. the percentage of paper for recycling utilisation compared to the total paper production): this corresponds to almost 48.3 million tonnes of paper for recycling utilised in paper and board production. At the same time, the recycling rate in Europe has been estimated at 72.3%. In Europe there are different national and regional collection systems for paper and different waste management companies supplying used paper. The progress towards meeting higher paper recycling targets are monitored by the European Paper Recycling Council (EPRC), which set out the targets in the European Declaration on Paper Recycling first published in 2000 and renewed every five years.

The system for processing paper for recycling varies according to the paper grade and the type of furnish used. Generally, the processing of recycled fibres (RCF) can be divided into two main categories:

- processes using exclusively mechanical cleaning, i.e. without deinking, comprising products like Testliner, corrugating medium, uncoated board and cartonboard;
- processes using mechanical cleaning and deinking comprising products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), coated board and cartonboard or market DIP.

The maintenance of the fibre cycle relies on the feed of a certain amount of primary fibres to ensure the strength and other properties of the paper to be produced.

In the tables below, the main raw materials for paper making process as summarized. At the same time, the major types of “waste from pulp, paper and cardboard production and processing” are reported, according to the European List of Waste (Commission Decision 2000/532/EC – consolidated version).

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### Table 15 - Papermaking process - Raw materials

<table>
<thead>
<tr>
<th>Raw materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Wood) pulp</td>
</tr>
<tr>
<td>Paper for recycling</td>
</tr>
<tr>
<td>Non-fibrous materials (e.g. fillers, coatings and chemical additives)</td>
</tr>
<tr>
<td>Other fibrous material (e.g. cotton, linen, bark, hemp, jute, straw and rags).</td>
</tr>
</tbody>
</table>

### Table 16 - Papermaking process – Main waste

<table>
<thead>
<tr>
<th>Main waste (03 03 wastes from pulp, paper and cardboard production and processing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03 03 01 waste bark and wood</td>
</tr>
<tr>
<td>03 03 02 green liquor sludge (from recovery of cooking liquor)</td>
</tr>
<tr>
<td>03 03 05 de-inking sludges from paper recycling</td>
</tr>
<tr>
<td>03 03 07 mechanically separated rejects from pulping of waste paper and cardboard</td>
</tr>
<tr>
<td>03 03 08 wastes from sorting of paper and cardboard destined for recycling</td>
</tr>
<tr>
<td>03 03 09 lime mud waste</td>
</tr>
<tr>
<td>03 03 10 fibre rejects, fibre-, filler- and coating-sludges from mechanical separation</td>
</tr>
</tbody>
</table>

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8 http://ietd.iipnetwork.org/content/pulp-and-paper

9 http://www.paperforrecycling.eu/
Pulp and paper mills typically generate significant quantities of non-hazardous solid waste which require management as a waste material or as a by-product.

Sludge, which is defined as “A suspension with high solids content as the type precipitated by sewage treatment” by JRC (2014), is one of the main waste of the papermaking process. Considering that about 40-50 kg of sludge (dry) is generated in the production of 1 tonne of paper at a paper mill [12], and that the total paper production corresponds to 92 million tonnes in Europe in 2017 [13], the total paper sludge production in Europe can be estimate approximately at 4 million tonnes per year.

The paper sludge is fundamentally composed of water, fiber, ink and a mineral load. After being dewatered, the sludge is often mixed with bark and burnt in the bark boiler. Other options are combustion in a biomass power plant, a fluidised bed sludge incinerator or in the recovery boiler. In other cases, the sludge is delivered to external waste management contractors for biogas production, disposal of landfill or other alternatives. Among these “other alternatives” there is the potential for industrial symbiosis: the sludge from paper mills can be utilized in the cement and brick industry (to improve porosity) or as another building material. Sludge from primary clarifiers (or mixed with excess sludge from biological treatment) that contains fibres, fines and inorganic compounds (e.g. fillers, coating pigments) is especially suitable for use in the cement industry, where both the material and energy content of the paper residues can be recovered. Waste paper sludge has the potential to partly replace cement in concrete and further waste paper sludge can be used as a fuel before using its ash as partial cement replacement due to its high calorific value.[14]

The sludge (about 50 % moisture content) is dried with waste heat from the pre-dryer of the cement kiln so that no additional thermal energy is needed to reduce the moisture of the sludge down to 10 – 15 %. Thus, when burning the dried sludge in the cement rotary kiln the calorific value of the organic substances is used and the ash from incineration of the sludge (mainly) remains in the product (cement). The inorganic substance of the ash of the incinerated sludge is also a compound of the cement clinker. The Dutch CDEM process (International Patent, 2006) represents a pioneering recovery system, where the paper sludge is treated at temperatures of around 730°C, in a fluidized bed combustion system; as other clayey materials, this waste has to be subjected to a process of thermal activation to provide it with pozzolanic properties of its mineral content. In addition, it is worth highlighting that the paper industry that uses 100% recycled paper as a primary material generates waste paper sludge which, by its nature, constitutes an inestimable source of kaolin - controlled calcination of waste (500-800°C) supplies an alternative approach to obtain recycled metakaolin, a highly pozzolanic material for the manufacture of commercial cements [15]. Experimental cements, based on paper sludge ash and ground granulated blast furnace slag (i.e. with no Portland cement content), have been produced and patented [16].

In general, it can be stated that if cement (or brick) manufacturing industries are close to the mill and are able to use the sludge it is a viable option – proximity is an aspect that has to be considered.

Other applications include fibrous sludges mixed with fly ash used for construction purposes, e.g. roads and storage fields [11] and the possibility to compost paper sludge or land spread suitable waste fractions in agriculture. The University of Twente designed a new pyrolysis system to separate paper sludge into bio-oils and minerals.10 Others evaluated the environmental performance of using pulp and paper sludge as feedstock for the production of second generation ethanol (due to its high polysaccharide content is a valuable feedstock for bioethanol production) and displayed significant environmental impact improvements [17]. Another possibility is the reutilization of the sludges in the paper and board industry itself - paper tests (caliper, breaking length, tear index, elongation, bursting strength, stiffness, opacity, whiteness, and porosity) and board tests (ring crush test, Concora medium test, corrugated crush test) demonstrated the feasibility of this application for at least 12 types of sludges [18]. Another project, the EffiSludge for LIFE project (An innovative concept to improve resource and energy efficiency in treatment of Pulp and Paper industry effluents), aimed to build and operate a plant able to increases the biogas potential from wastewater generated within the pulp and paper industry and at the same time to lower the electricity consumption by 50% [11].

According to the study “Analysis of certain waste streams and the potential of Industrial Symbiosis to promote waste as a resource for EU Industry”, prepared for the European Commission, paper industry can be an important part of the industrial networks in various clusters – examples are present in Syria, Austria; Guitang Group, China; Kawasaki, Japan [30]. Indeed the symbiosis potential of this industry include both the possibility to use paper for recycling as input
(upstream) and the possibility to use the waste generated during the paper making process in other industries, for other application (downstream).

**COPPER SLAG**

The copper industry, identified with the NACE codes given in Table below, is a major contributor to the global economy - in Europe, the annual production of copper is around 2.6 million tonnes, representing around 12% of global production. The main production sites are in Germany, Poland, Spain, Sweden, Finland, Belgium and Bulgaria.

Table 17 - NACE codes for copper industry

<table>
<thead>
<tr>
<th>NACE Rev. 2 codes for the copper industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
</tr>
<tr>
<td>24.4</td>
</tr>
<tr>
<td>24.4.4</td>
</tr>
</tbody>
</table>

Figure 12 shows the whole copper production chain, from the mining and processing of the raw material to the semi-fabricated products manufacturing. About 50% of raw material comes from mining, while the remaining 50% is bought on the market under copper scrap form. Copper is 100% recyclable; it can be perpetually recycled without loss of performance or quality. Copper recycling includes material collected from end-of-life products as well as the remelting of factory waste. It offers great advantages: the reduction of the exploitation of resources and the environmental impacts related to the copper production (smelting, converting and refining), the reduction in volume of waste sent to landfill and significantly energy saving (up to 85% less energy).

Figure 12 – Copper production chain (Source: European copper institute)

Copper slag is a waste obtained during the pyrometallurgical production of copper, by smelting, converting and refining processes and it is classified as EWC code 10 06 01 in the European List of Waste (Commission Decision 2000/532/EC – consolidated version).

Approximately 2.2-3 tons of copper slag are generated per ton of copper produced [19] and the global annual production of copper slag is about 24.6 million tons. The copper slag generation for different continents are depicted in the Table below [20].

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[12] https://copperalliance.eu/
According to the current regulatory framework, this waste is considered as non-hazardous waste. In fact, it does not cause environmental or human health problems if the lead content does not exceed the limit value of 0.3% [23].

Due to the huge amount of slag generated, the potential applications of copper slag have been investigated in the past few decades. Current options of management of copper slag are recycling, recovering of metal, production of value added products and disposal in dumps or stockpiles [24].

Figure 13 shows the conventional recycling process of copper residues [25]. The process consists in four main process steps: smelting, converting, pyrometallurgical refining and refining electrolysis. This process allows treating a broad variety of input material.

The copper slag obtained from matte smelting step, containing about 1-8% Cu, is sent to the slag cleaning process (highlighted in the flow chart) in order to produce valuable metals and saleable slag that can be used to produce different value added products.

Copper slag can be considered a promising source of secondary raw material: it can be used to produce different products, i.e. cement, concrete, fine aggregate, fill material, road base construction, abrasive material, roofing granules, cutting tools, railway ballast material, tiles and glass [21]. However, it has been estimated that copper slag is utilised in value added applications only about 15-20% of the copper slag generated, the rest of material is dumped as waste [22].

Established networks related to copper and non-ferrous metals markets already exist, such as the European Copper Institute [13] and Eurometaux [14]. They focus on sharing knowledge and experiences in the sector, including the waste management.

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**Table 18 - Copper slag generation in various regions**

<table>
<thead>
<tr>
<th>Regions</th>
<th>Copper slag generation (million tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia Europe</td>
<td>7.26</td>
</tr>
<tr>
<td>North America</td>
<td>5.90</td>
</tr>
<tr>
<td>Europe</td>
<td>5.56</td>
</tr>
<tr>
<td>South America</td>
<td>4.18</td>
</tr>
<tr>
<td>Africa</td>
<td>1.23</td>
</tr>
<tr>
<td>Oceania</td>
<td>0.45</td>
</tr>
</tbody>
</table>

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[14] https://eurometaux.eu/
The **European Copper Institute** (ECI) is part of Copper Alliance, which represents the network of regional international centres and their industry-leading members, which is led by the International Copper Association (ICA) with headquarters in Washington. The ECI members represent the majority of European copper production.

ECI mission is to contribute to growing the copper market, promoting a sustainable development.

The membership among copper producers, smelters, recyclers and fabricators offers important advantages such as:

- opportunity to connect with industry colleagues;
- use of the association as platform to meet the political and academic world;
- support in European and global advocacy and market outreach efforts,
- access to the global expertise;
- growth of the visibility, leveraging communications opportunities across European markets and participating in event organized at EU levels about various specified topics

**Eurometaux** is a network of non-ferrous metals producers and recyclers in Europe, including European metal associations. Eurometaux aims to promote sustainable production, use and recycling of non-ferrous metals in Europe. In addition to the existence of already established networks, there are companies specialized in supplying of copper slag or other type of waste such as Bulk Cementitious Material (LaFarge Group).  

**Bulk Cementitious Materials** (BMI) deals in the supply of cementitious materials like blast furnace slag, col fired power station by-product (fly ash, bottom ash, gypsum), silica fume and copper slag to the cement and construction industries. BMI also offers technical and marketing support to coal fired power stations and metallurgical industries concerning their by-products.

An important evidence of the potential of industrial symbiosis in this sector is the increasing interest in the valorisation of this type of waste. In fact, several events focusing on the circular economy and valorisation of waste topics have been organized such as:

- **World resources forum 2019** is an event that took place recently in Belgium, focused on circular economy topic. WRF2019 aims to share the knowledge and the best practices and connect different stakeholders. Among various partners, the European copper institute will take part in the conference.

- **The International Slag Valorisation Symposium** aims to contribute towards near zero-waste processing and closed material loops by offering to researchers and industrial actors the opportunity to share knowledge and critically discuss the challenges and opportunities in the field of slag valorisation.

  In particular, the last edition of The International Slag Valorisation Symposium was dedicated to the principle of industrial ecology for metallurgical residues as part of a Circular Economy, including the latest advances in the field (clean slag production, metal recovery, slag solidification, energy recuperation and slag based cements).

In the view of above, it can be concluded that the copper sector has already great familiarity with the circular economy concept and has already implemented industrial symbiosis with the construction materials value chain. Further evidence of this is that the European copper industry has invested substantially in the last years, to reduce the non-ferrous metal content in final copper slag in order to ensure their acceptance as construction products. Several studies about copper slag utilization in building material industries as well other type of applications have been conducted. No critic parameters of this waste are reported; rather many researches demonstrate that copper slag has good physical and mechanical properties such as good abrasion resistance, good stability property and excellent soundness and workability characteristics.

From the environmental and economic point of view, this IS can offer great opportunities. The use of copper slag in construction material industry allows obtaining revenues and avoiding the costs and environmental burdens related to landfilling, as well as wastage of metal value.
4. METHODOLOGY FOR REPLICABILITY EVALUATION

In this section, a methodology to assess the replicability potential of different identified IS opportunities is presented. This methodology aims to provide some instruments to preliminary assess the replicability potential of the FISSAC model in other sectors or other value chains, but it is not intended to be a tool to perform detailed assessments for evaluating the industrial symbiosis potential of each opportunity.

Two different kinds of assessment are provided: a qualitative approach and a quantitative approach. For the qualitative approach, a list of criteria that can guide a first evaluation of the replicability, through an evaluation scale, tailored to two objectives: addressing the replicability in other sectors, and in other countries, respectively. For the quantitative approach, two main phases of the analysis are proposed, firstly addressing replicability potential on the basis of traditional material flow analysis and Sankey diagram representation, and then allowing the evaluation of replicability potential also considering environmental and economic factors for the value chain assessed in FISSAC.

4.1 Qualitative assessment of replicability potential

4.1.1 Qualitative criteria for assessing replicability potential in other value chains

In order to evaluate the replicability potential for industrial symbiosis schemes in other sectors, a set of qualitative criteria have been identified. These criteria are aimed at investigating aspects of different nature, in order to cover all the possible opportunities and weaknesses for the scheme under analysis and to enable to identify main barriers and drivers for the implementation of such schemes. It is important to highlight that this set of criteria is outlined with the goal of assessing the potential for replication of the FISSAC model in different value chains, but it does not take into account specific conditions associated to geographic location or to national/regional context. Indeed, from case to case, these factors should be included when evaluating the possibility of replicating the FISSAC model and any industrial symbiosis scheme, because they may turn relevant and significant for the evaluation of effective costs and benefits of the symbiosis. For example, the proximity of two industries can be a proxy for exchange or transfer of material and/or energy flows and can make beneficial exchange practices that are not that effective in other locations. The same situation may appear in case incentives or tax reductions are in place in a certain country or region and they are effective in generating economic benefits for specific symbiosis schemes.

Below, the list of criteria, with a short description, is reported:

- **Existence of already established networks (industries, IS consultancy organizations, research, civil society, organizations, public authorities and policy makers):** in the baseline of FISSAC model, it has been identified the necessity to firstly establish and further develop a network of stakeholders, focused on sharing best practices and other Industrial symbiosis experiences, as starting point for the IS establishment. If a structured network of stakeholder already exists, it can play a fundamental role in the replicability of the FISSAC model;

- **Existence of innovative non-technological processes and initiatives:** the needs to rely on a solid network of relationships and to build trust among stakeholders are important conditions for the instauration of industrial symbiosis. Existence of innovative non-technological processes and initiatives to co-develop and promote the IS opportunity, such as workshops or Living Labs can really facilitate this aspect – within the FISSAC project Living Labs have been recognized as an important tool to detect and analyze drivers and barriers of IS;

- **Previous industrial Symbiosis experiences in the sector:** if the sector under evaluation has already implemented industrial symbiosis experience and it is already familiar with circular economy concepts, the adoption of the FISSAC model is facilitated;

- **Existence of previous and current IS initiatives at European and international level, for the specific waste material stream:** within FISSAC project, different applications have been identified for different industrial waste streams to be used for the production of innovative building products. Other initiatives or projects could be exploited to gain an understanding about other possible applications and they could represent a starting point for the replicability of the FISSAC model in different sectors;

- **Specific regulation on waste management:** the lack of distinction between wastes and secondary materials in EU-based regulations can deeply obstacle the exchange, reuse and recycle of wastes between companies. With this respect, the presence of a clear regulation framework dealing with the use of the specific waste material streams can strongly foster IS establishment;

- **Existence of technological processes able to transform waste into secondary raw materials:** certain types of waste, before their utilisation in another sector, need a technological processing able to transform them into...
secondary raw materials, guaranteeing the desired performances. In these cases, the existence of viable technological processes to treat the waste is a prerequisite for the IS establishment;

- **Technical and non-technical barriers affecting IS opportunity already identified:** different technical and non-technical barriers can be encountered when evaluating the possibility to establish an IS opportunity – their prompt identification is the first step for their resolution;

- **Availability of studies related to the environmental, H&S and economic impacts of the IS opportunity:** environmental and economic benefits can leverage the IS establishment – studies demonstrating the positive effects of the IS can really encourage its implementation, whilst issues on health and safety aspects can represent a critical factor for the feasibility of the solution;

- **Availability of studies related to social acceptance of this secondary raw material:** social engagement and acceptance have been tackled within the FISSAC project, since they have been recognized as important issues for the success of IS – studies demonstrating the social acceptance through the establishment of certain IS process can encourage its implementation;

- **Possibility to use FISSAC ICT Tool:** the FISSAC ICT tool is an instrument conceived to facilitate IS establishment – the possibility to use the tool can promote the IS, enlarging the network and evaluating the associated impacts.

A qualitative scale is associated to each criterion, to facilitate the use of this methodology and to guarantee a more objective assessment. In the Table the criteria for the assessment and associated grades, with correspondent explanation, are reported.

In general, grade 5 corresponds to a high potential for replicability, while grade 1 indicates a low potential, for each criterion.

**Table 19 - Evaluation matrix for replicability potential in other sectors**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grade</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence of already established networks (industries, IS consultancy organizations, research, civil society, organizations, public authorities and policy makers)</td>
<td>1</td>
<td>Previous failed experiences of establishing a network</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Absence of a network</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Existence of a network</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Existence of different networks</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Existence of a very strong local network</td>
</tr>
<tr>
<td>Existence of innovative non-technological processes and initiatives</td>
<td>1</td>
<td>Previous failed experiences of establishing innovative non-technological processes and initiatives</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Absence of previous initiative</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Example of a previous initiative</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Example of different initiatives</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Existence of numerous consolidated initiatives</td>
</tr>
<tr>
<td>Previous industrial Symbiosis experiences in the sector</td>
<td>1</td>
<td>Previous IS experiences with very weak results</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Previous IS experiences with weak results</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Previous IS experiences</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Previous IS experiences with good results</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Previous IS experiences with very good results</td>
</tr>
<tr>
<td>Existence of previous and current IS initiatives at European and international level, for the specific waste material stream</td>
<td>1</td>
<td>Previous failed experiences for the specific waste material stream</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Absence of previous initiative</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Example of a previous initiative</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Existence of numerous initiatives</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Existence of numerous successful initiatives</td>
</tr>
<tr>
<td>Specific regulation on waste management</td>
<td>1</td>
<td>Existence of a specific regulation, hindering the utilization of the specific waste stream</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Absence of a specific and clear regulations</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Existence of a specific regulation, not already implemented</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Existence of a specific regulation, already implemented</td>
</tr>
</tbody>
</table>
## Report on Industrial Segmentation, criteria and correlation to the FISSAC first application

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

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grade</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence of technological processes able to transform waste into secondary raw materials</td>
<td>5</td>
<td>Existence of a specific regulation, promoting the utilization of the specific waste stream</td>
</tr>
<tr>
<td>Technical and non-technical barriers affecting IS opportunity already identified</td>
<td>1</td>
<td>No information related to technical and non-technical barriers</td>
</tr>
<tr>
<td>Availability of studies related to the environmental, H&amp;S and economic impacts of the IS opportunity</td>
<td>1</td>
<td>No available studies</td>
</tr>
<tr>
<td>Availability of studies related to social acceptance of this secondary raw material</td>
<td>1</td>
<td>No available studies</td>
</tr>
<tr>
<td>Possibility to use the FISSAC ICT Tool</td>
<td>1</td>
<td>Presence of significant barriers related to the FISSAC ICT Tool utilization</td>
</tr>
</tbody>
</table>

In addition, it should be pointed out that even if these criteria are qualitative, some quantitative benchmarks may be introduced in order to refer to a baseline status during the assessment of the criteria, such as number of existing networks, number of viable technological processes, etc. These quantitative benchmarks could provide with an even more clear idea of the replicability potential associated to the opportunity under investigation.

### 4.1.2 Qualitative criteria for assessing replicability potential in other EU countries

In this section, a qualitative methodology for the evaluation of replicability potential of the FISSAC model in different EU countries is presented. As for the case of the assessment of replicability in other value chains, it is chosen to carry out the replicability assessment through the definition of multiple criteria. This approach guarantees the possibility to perform a comprehensive and holistic evaluation, focusing on a wide spectrum of factors influencing the potential for replicability of a model. Furthermore, to each criterion a qualitative scale is associated, in order to guide the end-users of the methodology through the assessment and to guarantee an objective comparability of results obtained for different countries.

Below, the list of criteria, with a short description, is reported:

- **Support of government to improve industrial symbiosis and circular economy:** opportunities and drivers promoted by governments may act as determinant facilitators for the implementation of industrial symbiosis strategies and thus for a successful application of the FISSAC model. Main instruments through which governments can support industrial symbiosis include, among others, legislative framework i.e. laws, rules, decrees, etc., fiscal incentives, reduction of paperwork burden;
- **Role of enterprises in promoting industrial symbiosis and circular economy:** in countries where enterprises and industries are traditionally engaged and interested in the creation of synergies and linkages, the...
application of the FISSAC model can be easier and more fruitful than under circumstances in which there is no interest for industrial symbiosis strategies. Furthermore, stakeholders can play a significant role in encouraging the development and implementation of actions of governments in the perspective of symbiosis and circular economy;

- **Clusterization of industries on territory**: the location and level of aggregation of industrial areas on the territory influences the way and the possibility of implementing industrial synergies. For example, if industries are highly clusterized within a country i.e. they are concentrated in industrial areas, easily accessible, exchanges between them can be implemented with limited effort. On the other hand, if industries are typically spread in different locations, which can also be isolated, interconnections may turn complex from a logistic and technical point of view;

- **Recovery and recycling rates**: values of recovery and recycling rates for material commonly monitored within the European Union, for those waste flows for which recovery targets are in force, may work as a powerful indicator of the possibility of implementing the FISSAC model within a European country. Indeed, to this rate aspects such as the attitude of governments, the availability of technological options for reprocessing waste and materials and economic feasibility, are connected;

- **Awareness of industrial symbiosis and circular economy principles among citizens**: level of awareness about industrial symbiosis and circular economy principles among citizens are influential because they can support the spreading of these practices and the use of the FISSAC model also at very small scales (e.g. SMEs). Furthermore, high awareness may lead to a more conscious selection of environmentally friendly products by the consumers;

- **Skills on information technology**: considering that a main component of the FISSAC model is constituted by the web-based platform, it is important that potential end-users of the FISSAC model have the capabilities of interacting with technological equipment and have high levels of confidence with ICT tools;

In the Table below the criteria for the assessment and associated grades, with correspondent explanation, are summarized.

**Table 20 - Evaluation matrix for replicability potential in other EU countries**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Grade</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support of government to improve industrial symbiosis and circular economy</td>
<td>1</td>
<td>Absence of support from the government</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Insufficient support from the government</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Fair support from the government</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Good support from the government</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Excellent support from the government</td>
</tr>
<tr>
<td>Role of enterprises in promoting in promoting industrial symbiosis and circular economy</td>
<td>1</td>
<td>Absent</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Insufficient</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Fair</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>Clusterization of industries on territory</td>
<td>1</td>
<td>Highly spread in isolated areas</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Mostly spread in isolated areas</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Balanced distribution on territory</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Mostly clusterized in easily accessible areas</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Highly clusterized in easily accessible areas</td>
</tr>
<tr>
<td>Recovery and recycling rates</td>
<td>1</td>
<td>Absence of information easily accessible and retrievable</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Rates steadily below the EU targets for most of waste flows, and/or decreasing trends</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Rates overall in line with the EU targets</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Rates overall in line with the EU targets and increasing trends for most of waste flows</td>
</tr>
</tbody>
</table>
When applying the aforementioned methodology, the following steps should be ideally carried out:
- analysis of national legislative framework;
- consultation with local stakeholders and decision makers;
- identification of the state-of-art as with respect to the level of implementation of industrial symbiosis schemes and circular economy schemes;
- assessment of the score for each criterion.

In order to understand the magnitude of impacts associated to the implementation of the FISSAC model within the analyzed country, the methodology should be applied for the baseline scenario, representing the current status of the country, and for a scenario foreseen in case the FISSAC model is actually implemented.

### 4.1.3 Output of the qualitative assessment

The application of the qualitative assessment methodology, both for the investigation of the potential of the value chain with respect to IS practices and for the analysis of country specific features with respect to IS and circular economy, is aimed at establishing a framework of opportunities and challenges for the replicability of the FISSAC model. It is worth noticing that the accuracy of the results is strongly dependent on the approach chosen for the evaluation of the criteria (e.g. compilation by a representative panel of experts, compilation based on review of the state of art, etc.).

A synthetic output of the qualitative analysis can be represented by a SWOT analysis illustrating strengths, weaknesses, opportunities and threats for the replicability of the FISSAC model within a certain sector in a certain country.

An interesting example of qualitative assessment of the potentials of industrial symbiosis in some Nordic European Countries is reported in the study “The potential of industrial symbiosis as a key driver of green growth in Nordic regions” [26]. Indeed, following a comprehensive review of the state of the art in the industrial sector and in the policy framework for each of the analyzed areas, key opportunities and drivers are identified. Examples of opportunities include interest from local manufacturing industry, focus on renewable energy and resource efficiency, while an example of challenge is the lack of long-term support schemes for innovative projects.

### 4.2 Quantitative assessment of replicability potential

#### 4.2.1 Quantitative methodology for assessment of replicability potential

In order to create a solid framework for the assessment of replicability potential, the qualitative criteria described in the previous section are coupled with a quantitative approach.

The methodology proposed is intended to be applied in parallel with the assessment of potential replicability through the qualitative criteria. Indeed, for a successful replication of the FISSAC model it is fundamental that both the results of the qualitative analysis and of the quantitative analysis are positive, as the two approaches are complementary. As a matter of fact, the qualitative assessment is focused on “framework conditions”, dealing mainly with legislative background, social aspects, technological issues that may positively or negatively interact with the implementation of
the FISSAC model, while the quantitative assessment is aimed at a specific analysis of main material flows available for industrial symbiosis.

Moreover, this quantitative approach is intended also to be applicable to evaluate the replicability of the industrial symbiosis opportunities investigated within the project (FISSAC value chains).

The quantitative methodology introduced is intentionally simple, schematic and synthetic, with the aim of being effective at capturing the overall features of the industrial segments for which the potential for application of the FISSAC model and of industrial symbiosis practices is being evaluated. Furthermore, it is flexible in the sense that:

- it can be applied either at local scale or at national/international scale;
- it can be adjusted on the basis of available data;
- it can take into consideration various proxies for replicability, such as volumes of flows, economic value of flows, etc.;
- relying on concepts commonly used for the assessment of circular economy or industrial symbiosis levels, it can be referred to make comparisons with other existing studies.

The core concepts of the methodology are extracted and expanded from the JRC Technical Report “Development of a Sankey Diagram of Material Flows in the EU Economy based on Eurostat Data” [27]. Basically, acknowledging that reliable and robust information on materials stocks and flows is considered among the prerequisites for a deeper understanding and a better monitoring of the effectiveness of different industrial strategies and for the promotion of innovation. The need of identifying and quantifying material stocks and flows within a fixed boundary (e.g. Europe, industrial park, etc.) is thus a fundamental concept for the proposed methodology. A large amount of data with reference to various materials flows is readily available to end-users within the European Union, in line with the effort of the European Commission to push circular economy and industrial symbiosis practices in order to increase sustainability within the European society. However, data are often segmented, unspecific and uncertain. For this reason, it is deemed very important that a methodology for the assessment of replication potential is implementable by using multiple data sources that may help in filling existing data gaps.

The methodology is built on the principles of Material Flow Analysis (MFA), which can be defined as a “systematic assessment of the flows and the stocks of materials within a system defined in space and time”. MFA thus consists in a quantitative analysis of mass flows within a system, based on the principle of mass conservation and it is applied in various industrial areas in order to control pathways for material use and industrial processes, to create loop-closing industrial practices to balance industrial input and output to natural ecosystem capacity. Furthermore, MFA-based approaches have been used widely over the past decade to characterize the life cycles of materials and substances [28]. Some concepts of MFA have already been applied within the FISSAC project with respect to the case studies flows. For example, in D1.3 of FISSAC project, detailed material and energy flows are identified with the aim of, among other, of identifying flows of recycled waste that are considered as key performance indicators for the development of FISSAC activities, and specifically the identification of barriers to industrial symbiosis.

Within the tailored methodology, MFA principles and concepts can be easily implemented and visualized through a Sankey diagram of material flows. A Sankey diagram illustrates flows and stocks of any kind, each characterized by an origin, a destination and an intensity; usually the dimension of the flows pictured is proportional to the intensity of the flow. Also additional information, apart those already introduced, may be included in the graph to give a better overview of the system. It is particularly suitable for the representation of systems/processes with a limited number of interactions and networking bounds, while it is not the best scheme — given its natural simplicity — to capture the features of systems with a significant number of transformations and interactions. With respect to this last aspect, is that the Sankey diagram may not be accurate enough to represent the level of detail necessary for certain systems or for certain purposes.

The Sankey diagram can be easily generated on the basis of readily available statistical information on material flows, provided that boundaries are properly fixed. With respect to industrial symbiosis and circular economy approaches, it can be a powerful mean to understand the strength and the potential associated to primary and secondary sources and as a starting point to define strategies for the development of symbioses aimed at a wise and responsible material use and at environment protection. Another advantage of this type of representation is that it can be easily updated, especially if interactions and flows change only in terms of intensity.

Recently, based on material flow accounts and waste statistics, research entities and governments have begun to monitor the economy-wide flow of major material categories in countries and regions, and show their level of
circularity. Furthermore, this approach has also been used by smaller entities, such as industrial parks, to represent interconnections between the components of the system. Just to give a clear example, Figure 14 shows the homepage of Kalundborg Industrial Symbiosis – one of the most well-known and established implementation of industrial symbiosis concepts in Europe - website\(^{18}\), where an interactive Sankey diagram is used to represent the existing symbioses.

**Figure 14 - Interactive Sankey Diagram, Kalundborg symbiosis**

![Interactive Sankey Diagram, Kalundborg symbiosis](image)

Figure 15 shows a schematic representation of a Sankey diagram adapted for the representation of a defined material flow (a material flow may also represent flows of multiple materials) within a generic industrial segment for a given time frame (e.g. one year).

**Figure 15 - Sankey diagram (adapted from JRC Technical Report [27])**

![Sankey diagram](image)

In the diagram, the following definitions can be assumed:

- **direct material input**: total mass of input material within the segment considered, including recycled and recovered material and material from other economies;
- **end of life waste collection**: total mass of output (i.e. waste) material from the segment considered;
- **waste treatment**: total mass of material used for energy recovery or landfilled;

\(^{18}\) [http://www.symbiosis.dk/en/]
- **other economies**: total mass of material exchange with different industrial segments.

This fixed points of the diagram are then connected with material flows. All the flows contribute to the overall mass balance of the system.

When focusing on industrial symbiosis, the sub-system (and associated mass) “other economies” acquires significant relevance, as it represents the quantity of material dedicated to symbiosis practices. Considering the final aim of defining a methodology for assessing replication potential, a set of indicators is extrapolated from the Sankey diagram representation, namely: generated waste, recycled material, material to other economies (output), secondary material and material from other economies. Indicators are defined as follows:

- **waste generation**: amount of waste generated. This indicator represents a measure of downstream flows available for industrial symbiosis and circular economy practices, as if a sector does not produce any waste there is no possibility of downstreams interconnections with other sectors. Nevertheless, it is highlighted that recycling operations are not viable for all the waste flows, either from a technical or economic perspective, and, thus, a high value of waste generation factor does not necessarily imply high potential for symbiosis;

- **recycled material**: amount of waste generated that is recycled. This indicator represents a measure of downstream flows available for industrial symbiosis and circular economy practices, as it gives an overview of the waste material generated that is currently treated and for which recycle processes are thus available and commonly performed. A certain amount of recycled material may thus be dedicate to industrial symbiosis activities;

- **material to other economies**: amount of output material diverted to other economies. This indicator represents a measure of downstream flows available specifically for industrial symbiosis practices. A high value of this indicator corresponds to a high degree of downstream interconnections for the segment studied;

- **secondary material**: amount of recycled or recovered material used as input material. This indicator represents a measure of upstream flows available for industrial symbiosis and circular economy practices;

- **material from other economies**: amount of material from other economies used as input material. A high value of this indicator corresponds to a high degree of upstream interconnections for the segment studied.

It is clear that the indicators “waste generation”, “recycled material” and “material to other economies” measure, at different levels of detail, the potential for the creation of industrial symbiosis schemes in the downstream processes of the segment, while the indicators “secondary material” and “material from other economies” measure the potential for the creation of industrial symbiosis schemes in the upstream processes of the segment.

The choice of calculating one or more indicators, and which indicator to be calculated, depends on the required level of detail for the analysis and on data availability for the sector studied. Furthermore, indicators can be calculated either for an existing scenario, with available data, or for a projected scenario, based on significant assumptions, with data assumed by stakeholders and experts.

When aiming at the evaluation of potential for replicability of industrial symbiosis schemes between two different segments, the steps below should be followed:

- identification of two segments;
- identification of the flow(s) they have in common;
- selection of the flow for which symbiosis schemes are considered;
- representation of each segment on a Sankey diagram dedicated to the flow studied;
- calculation of at least one upstream and one downstream indicator for each segment for the selected flow;
- assessment of possible matching between an upstream (downstream) with a downstream (upstream) indicator of each segment;
- assessment of the replication potential. Thus, if the matching is consistent, the replication is feasible.

It should be highlighted that the methodology presented assesses the potential for replicability of the FISSAC model in other industrial sectors and segments only based on available material flows. However, it is clear that the potential is also strongly influenced by economic and environmental factors. In this sense, the Sankey diagram representation may also be used to track main costs/benefits and main environmental impacts/benefits associated to the various flows and various scenario. A baseline scenario should always be assumed in order to evaluate the effectiveness of the industrial symbiosis from multiple perspectives.
4.3 Expanded quantitative methodology for assessment of FISSAC value chains

With the goal of addressing more in depth and from a holistic perspective the issues of replicability for the value chains studied within the FISSAC project at EU level, the quantitative methodology introduced in the previous section is expanded in this section, focusing on economic and environmental benefits of replicating industrial symbiosis for FISSAC value chains. This detailed analysis can be realized thanks to the data collected from the life cycle analyses of FISSAC streams performed in other Work Packages of this project, whilst, for other streams, the difficulty in data gathering may limit the possibility of applying this expanded methodology obtaining results with sufficient level of accuracy.

The assessment of environmental and economic performance associated with FISSAC value chains is developed on the basis of the general methodology previously introduced and it should be considered as a subsequent step to its application. Indeed, the core idea is to associate to each flow identified within the Sankey diagram a measure of environmental impact or benefit and/or a measure of economic value, in order to assess the overall performance of the industrial symbiosis scheme identified. In detail, the following steps should be followed:

- **representation of the studied system on a Sankey diagram**, including information about mass flows as explained in the previous section;
- **identification of relevant flows** for the analysis performed (i.e.: economic or environmental). This step is important to calibrate the accuracy of the analysis and the level of detail sought for the results; as a matter of fact, it can happen that flows that are significant in mass are not relevant from the economic or environmental perspective or, vice versa, flows that are not particularly significant in term of mass can influence the economic or environmental balance of the industrial symbiosis scheme. A common approach for the identification of relevant flows, is to assume a cut off rule (e.g. the flows having an economic value lower than 5% the value of the correspondent quantity of virgin raw material are to be discarded);
- **measurement of environmental or economic performance of each flow**. This measure is usually proportional to the mass of the flow, and can be obtained through various factors, that can be found either in literature or, as in this case, they can be retrieved from life cycle analyses. In this step, the selection of a significant measure for the purpose of the study is a key task and it will be discussed below.
- **overall balance of the system** within the boundaries of the study, in order to assess its performance from the desired perspective.

The expanded methodology shall be applied to a baseline scenario (e.g. current state of art) and to a scenario where the FISSAC model and an industrial symbiosis scheme is implemented. The comparison of the final balances allows to assess the potential for replicability in economic and environmental terms. These findings can also support the comparison between the replicability potential of the FISSAC model in different value chains.

As previously mentioned, it is worth pointing out that the selection of a suitable unit of measure of environmental or economic performance is fundamental to obtain significant and representative results from the analysis. As far as environmental performance is concerned, a widely used way of measuring the environmental impacts or benefits of a flow is using CO$_2$e emission factors (defined as the specific amount of CO$_2$e emitted by a certain flow), which are a measure of global warming potential, which is often an accurate proxy for the overall environmental impacts. As far as the economic performance is concerned, costs or income associated to each flow can be used as unit of measure for environmental performance. If a deeper level of detail is sought, aspects such as funds availability or incentives can be taken into account.

The best condition for replicability is reached when – in a given scheme of symbiosis – impact to the environment are reduced with respect to the baseline scenario and economic incomes increase with respect to the baseline scenario.

In the sub-section below, two examples of studies where approaches similar to the one proposed above are presented. Even though they are not specifically referred to the topic of industrial symbiosis, but deal with the wider framework of circular economy, they are considered as important for the understanding of the methodology here proposed for the assessment of replicability potential of the FISSAC model.
Examples of similar approaches in the wider framework of Circular Economy

The study “Treating Waste as a Resource for the EU Industry. Analysis of Various Waste Streams and the Competitiveness of their Client Industries” performed by the ECSIP Consortium [29] suggests a similar methodology to assess the progress towards circular economy within a country for a given sector. Specifically, the main assumption underlying the methodology presented in the report is that circular economy is reached when economic growth trend in time is decoupled from the trend of resource consumption and of environmental impacts within the sector, as shown in Figure 16.

*Figure 16 - Progress towards circular economy [29]*

In the study, the economic value of the sector is expressed by the Gross Value Added (GVA), which reflects - at country level - the value of goods and services produced, depurated by the costs associated to all inputs and raw materials that can be directly attributed to good or service. Environmental impacts are calculated with the same approach proposed in the previous section, by referring to GHG emissions associated with production using virgin raw materials on one side and using recycled secondary raw materials on the other side.

This study shows a comprehensive approach for the assessment of the performance of a circular economy strategies. It could be used – provided that data are available – also for the assessment of industrial symbiosis schemes. The drawbacks for the direct application of this methodology in this phase of the FISSAC project is that it is calibrated and created for a wide-scale assessment (country level) and that require specific market analyses to foresee GVA values for the scenarios where IS strategies are in place.

Another interesting example dealing with the assessment of the environmental performance of circular economy scenarios within the Construction & Demolition Waste (CDW) sector in Italy is found in a study recently developed by RINA-C for HISER Project (EU Horizon 2020 research and innovation program – GA 642085). In detail, the study is aimed at evaluating potential environmental savings gained by substituting primary material with secondary material within the construction value chain. Also in this study, the key parameter to compare environmental performances is the impact factor, measuring net benefits gained by recycling a certain mass of waste instead of introducing primary material in terms of Global Warming Potential (GWP).

The circular economy scenarios, whose details are not relevant for this report, are generated by modifying recovery rates and recovery routes of different streams of CDW materials, while the reference scenarios correspond to the current recovery rates and to the recovery rates foreseen by the Waste Framework Directive [19]. Results obtained are shown in Figure 17 below.

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This study is useful to illustrate which kind and form of results can be obtained by applying the expanded methodology proposed in this section. Furthermore, it shows how direct and objective comparisons between different scenarios are useful to assess which situations and strategies lead to a greater potential for replicability, being associated to most relevant benefits and savings.
5. CONCLUSIONS

In this document, a comprehensive methodology for the evaluation of replicability potential of the FISSAC model has been reported. It is important to highlight that the developed approach is aimed to include - as object of the assessment - both replicability in other European countries, and other industrial segments not already included in the FISSAC project.

In order to identify new possible sectors with industrial symbiosis potential across the extended construction value chain, the segmentation of the industrial sectors in a sequential way, starting from the ones having more proximity with the FISSAC case studies, represents a structured pattern to organize the two-fold analysis. On this basis, some examples of sectors that are potentially suitable for a detailed investigation have been already identified.

Since the developed methodology for the assessment of replicability potential is subdivided into a qualitative analysis and a quantitative analysis, to be applied in parallel, for a successful replication of the FISSAC model it will be fundamental that the results of both the assessments are positive.

Furthermore, the quantitative approach developed will also allow the evaluation of the replicability of the industrial symbiosis opportunities that are object of case study within FISSAC project, addressing economic and environmental aspects – investigated in WP3 – towards a sectorial scale.

As a direct follow-up of the activities described and reported in this deliverable, within D7.5, “Project Validation, SWOT and Concept replicability”, the here defined criteria and protocol will be applied in order to assess in detail the replication potential in other geographical and sectorial contexts.
6. REFERENCES

[23] Katrien Delbeke, Position Paper, European Copper Institute, January 2014