



Total Resource and Energy Efficiency
Management System for Process Industries

Deliverable 4.3

Toolkit for industrial symbiosis

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WP4 Industrial Symbiosis

T4.3 Toolkit for industrial symbiosis (T4IS) with the four HOW TOs

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Executive Summary

The MAESTRI project aims to tackle improvements in the impact of manufacturing activities at both company level and system level in order to achieve significant results. A holistic approach will enable process monitoring and optimization, as well as focus on an integrated and cross-sectorial interaction that can have a greater impact within the process industry. MAESTRI project encompasses an Industrial Symbiosis (IS) approach, which, within the scope of sustainable manufacturing for process industries, fosters the sharing of resources (energy, water, residues and recycled materials) between different processes of a single company or between multiple companies.

Findings from previous MAESTRI activities indicate that the appropriateness of the IS solutions is strongly influenced by contextual factors. Some specific characteristics will shape the scope and opportunities for IS in a specific context. These include but are not limited to: company size and production processes, geographical landscape and regional industrialization as well as country-specific trade regulations and policy. The high degree of characterization needed for the design of IS in different contexts means practitioners would benefit from support (e.g. tools and methods) developed specifically to address contextualization challenges for IS design and planning. There is a need to provide companies with structured and systematic ways to uncover the latent value in waste resources and to support the adaptation to each particular business context and the identification of opportunities at local / regional level.

This document presents the Toolkit for Industrial Symbiosis (T4IS) built upon four guiding questions, the four HOW TOs: How to SEE waste, How to CHARACTERISE waste, How to VALUE waste and How to EXPLOIT waste. These guiding questions represent the main steps in a development process for IS exchanges.

The focus of WP4 within MAESTRI project is to provide companies with methods and tools to develop self-organising IS to the extent that this is possible. The T4IS described in this document constitutes a complete first stage prototype tools and methods, capable of being fully used by industrial partners. This will be refined during MAESTRI demonstration phase and a final version of the T4IS will be created by the end of MAESTRI project.

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Abbreviations

CAS	Chemical Abstracts Service	IS DATA	Industrial Symbiosis DATA repository
CASRN®	Chemical Abstracts Service Registry Number	IUPAC	International Union of Pure and Applied Chemistry
CPA	Classification of Products by Activity	LCA	Life Cycle Assessment
EC	European Commission	MSM	Multi-Layer Stream Mapping
ECHA	European Chemical Agency	NACE	Nomenclature générale des Activités économiques dans les Communautés Européennes
EC Number	European Community Number	NAPCS	North American Product Classification System
ecoPROSYS	Eco-Efficiency Integrated Methodology for Production System	T4IS	Toolkit for Industrial Symbiosis
EOV	Eco Orbit View	VSM	Value Stream Mapping
EWC	European Waste Catalogue		
InChI	International Chemical Identifier		
IS	Industrial Symbiosis		

Definitions

By-product > a production residue that is not a waste, also referred to as non-waste by-product. It is a substance or object, resulting from a production process, the primary aim of which is not the production of that item; the substance or object's use is certain, possible without further processing and it is produced as an integral part of the production process (EUROPEAN COMMISSION, 2007)

Categorisation > the action or process of placing into classes or groups; a system of classes into which something is sorted (OXFORDDICTIONARIES.COM, 2017)

Characterisation > A description of the distinctive nature or features of someone or something (OXFORDDICTIONARIES.COM, 2017)

Chemical property > a property of a substance relating to its chemical reactivity (MERRIAM-WEBSTER.COM, 2017)

Classification > the action or process of classifying something; a category into which something is put (OXFORDDICTIONARIES.COM, 2017)

Complementary tool > this refers to a tool or method developed within MAESTRI project with potential to complement the primary tool or method proposed in the steps of the T4IS

Industrial Symbiosis (IS) > It encourages companies to adopt a collaborative approach in all aspects of their business so that resources can be recovered, reprocessed and reused elsewhere in the industrial network either by themselves or by other companies (WRAP, 2014).

Physical property > a property (as colour, hardness, boiling point) of matter not involving in its manifestation a chemical change (MERRIAM-WEBSTER.COM, 2017)

Primary tool > this term refers to a tool or method suggested to support the steps of the T4IS

Product > all material that is deliberately created in a production process (EUROPEAN COMMISSION, 2007)

Production residue > a material that is not deliberately produced in a production process but may or may not be a waste (EUROPEAN COMMISSION, 2007)

Secondary outputs > this term refers to outcomes of production processes that are not deliberately produced, not only material outputs

Secondary tool > this term refers to tools or methods that have not been developed within MAESTRI project and could be used additionally in the steps of the T4IS.

Value uncaptured > potential value that could be captured but has not yet been captured (YANG ET AL., 2017)

Waste > It is any substance or object which the holder discards or intends or is required to discard (EC, 2008).

Waste management > It regards to the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker (EC, 2008).

1 Introduction

This initial section provides an introduction to the work developed within task 4.3 “Toolkit for industrial symbiosis (T4IS) with the four HOW TOs” and the Toolkit for Industrial Symbiosis (T4IS), its purpose and its development process.

1.1 Background

Industrial Symbiosis (IS) is “*principally concerned with the recovery and reuse of wastes (materials, water, or energy) from one industry as alternative input in a neighbouring facility*” (VAN BERKEL, 2009). There are different types of IS related exchanges. They can occur as a one-off material waste exchange between two parties or in more continuous flows exchanged within factory or organisation boundaries or between different companies with a certain geographic proximity (CHERTOW, 2000). The entities participating in IS could be either companies or factories as IS opportunities arise at process level (LOMBARDI and LAYBOURN, 2012). Therefore, the IS concept can cover both, the cases in which IS opportunities are realised by a single company (intra-firm IS) and those realised in partnership with other companies (inter-firm IS).

The development of IS can be seen as a dynamic process leading to the creation of industrial ecosystems, within which new opportunities are expected to emerge over time (Liu et al., 2011). IS design, planning and implementation seems to be very frequently an ad hoc process built up for each specific context. It is mainly an iterative process rather than a linear process, and mostly incremental rather than radical.

The appropriateness of the solutions is strongly influenced by contextual factors. These include but are not limited to: company size and production processes, geographical landscape and regional industrialization as well as country-specific trade regulations and policy. The high degree of characterization needed for the design of IS in different contexts means practitioners would benefit from support (e.g. tools and methods) developed specifically to address contextualization challenges for IS design and planning. This is the overall purpose of WP4 “Industrial Symbiosis” within MAESTRI project.

A summary of previous Deliverables within MAESTRI Work Package 4 “Industrial Symbiosis” is provided next.

Deliverable D4.1 “Report on challenges and key success factors and gap analysis for industrial symbiosis” (HOLGADO AND EVANS, 2017) adopted a two-side approach in order to understand the challenges and success factors in engaging with and implementing an IS approach to improve resource efficiency. One side looked at state-of-the-art advances in literature and the other side focused on the state-of-practice in an exploratory study with IS practitioners. The literature review and analysis introduced an overview of general challenges and success factors as well as their differences related to different ways of arranging IS implementations: self-organised, planned and facilitated processes. The key difference between these three arrangements is the way in which they emerge (Holgado et al., 2016): self-organised IS emerges unprompted from the interactions between companies as serendipitous arrangements; planned IS is used in the design of industrial estates and eco-industrial parks (Singhal and Kapur, 2002, Gibbs and Deutz, 2007); and facilitated IS is enabled by a third party making an intervention during a period of time

(Paquin and Howard-Grenville, 2009). Facilitation and coordination could also be seen as part of the evolution of IS after its initial establishment in order to enhance the potential opportunities for collaboration (Chertow and Ehrenfeld, 2012).

The practitioners' viewpoint on challenges and success factors was collected through a set of 16 interviews. The data collected was analysed and a set of 33 challenges and 34 success factors were identified and categorised according to three stages in IS development processes. A summary of findings most relevant for toolkit development is provided herein.

Taking the perspective of the company seeking solutions for their waste and by-products, it is important to find a reuse solution that:

- takes advantage of the nature of the material and maximises its remaining value;
- addresses a market need that matches the size of the possible material supply.

At opportunity identification phase, the main challenges identified relate to:

- *Analysing and characterising their waste streams by companies themselves demand internal resources and extra time.* Sometimes the specification of the waste material is changing over time due to the plan of production or a change of the product portfolio. This makes it even harder to find a potential use for it. Once this is done, it is difficult for them to identify what to do next.
- *Identification of potential reuse solutions and potential target users by companies themselves* by using in-house laboratories, by partnering with research institutions or even by running ideas competitions with external institutions.
- *Dealing with regulations by themselves require internal resources and extra time / investment.* In some cases the waste materials cannot be traded if they are not included in a by-products catalogue, therefore, if the potential user is interested enough, both companies can start the process to introduce the waste into the catalogue as a by-product. This process is full of paperwork and can take from months to years. The procedure to commercialise by-products is often found discouraging and it seems to be worth the effort only for large quantities of waste/by-products.
- *Additionally, materials categorised as waste can only be handled by authorised waste management companies, thus, companies do not have rights to manage / transport their own waste even between sites of the same company.*

Some companies partner with recycling companies, which find a solution for their waste materials. This partnership enables the pre-treatment of the waste materials before it can be used by the potential buyers. This seems to be a beneficial solution for all parties involved, even though the burden of understanding the volume for break-even point may reside on the waste producing company as well as the search for potential buyers.

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Regarding IS exchanges design and planning, concerns arise in regards to potential scarcity of suppliers / buyers, high dependency on a particular solution and transport restrictions / costs between different locations.

In fast changing industries, where companies underlie a continuous adaption process to fulfil the market needs, it may not be advisable to agree a long term contract for delivery for waste material or energy. Particularly, small companies find it difficult to collaborate with

large companies, even if they are the most adequate partners to pursue the IS opportunity. There seems to be a size mismatch problem that make partnerships difficult due to company size and working practices.

In some cases, an identified IS opportunity reached the level of design and planning, however, it did not get implemented due to high investment needed without long term guarantee of continuity or due to the business failure of one of the companies involved. Some companies have found that collaboration with competitors is a way of achieving enough volume to make the IS opportunity viable.

Furthermore, key success factors identified for IS exchanges implementation and progress over time are:

- Transparency and information sharing among IS partners;
- Creating reputation and credibility as stable IS partner;
- Keeping a learning approach to explore different implementation paths;
- Creating an embedded approach for IS within business operations.

The results of these activities have informed other tasks in WP4, namely the definition of a library of case studies and the design of a waste database as well as contributed to set up the foundation for the development of the toolkit.

Deliverable D4.2 “Prototype library of case studies linked to a waste database” (BENEDETTI ET AL., 2017) presented a prototype library of case studies and the linked waste database that have been developed in task 4.2 (“Library of case studies and open source database of waste”). The main purpose of the library and the database is to allow users to gather new ideas for the implementation of new IS exchanges.

The library is designed to give helpful insights on how IS has been a successful approach to face resource efficiency and operational challenges. It allows to have an overview of the IS implementation process in different cases and to understand the efforts needed in terms of analyses required, knowledge acquisition, people, time, investments, etc.

The library of case studies is a collection of cases available in literature (from scientific papers, conference papers, websites, whitepapers, conference presentations, etc.), described with reference to the original source. The description is divided into five sections in order to categorise the content and make it more easily available:

- 1) the challenge or triggering factor that motivated the company/companies to implement IS;
- 2) the main barriers encountered in IS implementation;
- 3) the approach used by the companies involved to overcome such barriers;
- 4) the discovery process, i.e. the process that led from the initial challenge to the IS implementation;
- 5) the preconditions or antecedents, i.e. the contextual factors that made the IS implementation feasible.

The database is designed to provide companies willing to implement IS with examples of symbiotic exchanges already implemented by other companies in the same sector or with a specific waste material. This is enabled by using European classifications:

- The “Nomenclature statistique des activités économiques dans la Communauté européenne” (NACE), or “statistical classification of economic activities in the European Community” is originally designed to allow the comparability of economic statistics produced by different European institutions (EUROSTAT, 2008). It is currently used in Europe and other Countries all over the world to easily identify industrial sectors and other productive economic activities. It has a hierarchical structure with four level of details: a NACE code is constituted of two up to six digits, and each couple of digits provides additional details on the type of activity considered (EUROSTAT, 2008).
- The European Waste Catalogue (EWC) is a European classification that identifies and describes waste into categories according to the process with which they have been produced (represented by the first two of the six digits forming the waste code, and partly referred to NACE classification). It includes industrial and urban waste, hazardous and non-hazardous materials (hazardous properties are specified for each code) (EUROPEAN COMMISSION, 2008).

The database is a spreadsheet that lists all the exchanges described in the cases collected within the library. It provides information regarding involved companies, including donor and receiver company, as well as companies involved in waste treatment process (i.e. name of the company where available and industrial sector identified using the NACE code) and information regarding the exchanged material (i.e. brief description, EWC code where available, treatment needed). In addition, it reports the final use of the waste resource, the actor paying for the transaction, the level of completion of the exchange described and the possibility to get information related to quantities in the original source.

Two standard queries (looking for similar companies and looking for exchanges of similar waste materials) have also been designed to help users retrieve useful information from the database and the library.

The library and database have been populated with 46 case studies and 426 corresponding exchanges. The structure of the repositories and the standard queries designed have been tested with the help of MAESTRI partners, who provided their NACE and EWC codes. These codes have been used to perform the queries and retrieve information on the industrial sector and waste materials of each partner. The 20% of the analysed codes showed matchings with library and database entries, corresponding to 38 exchanges in the database and 19 cases in the library, linked to 16 different sources.

The library and database designed in MAESTRI T4.2 “Library of case studies and open source database of waste” represent an innovation compared to available knowledge repositories for IS. In fact, while several tools have been developed over the last years to help companies identifying IS opportunities, an activity that has been recognised to be critical for IS implementation (GRANT ET AL., 2010), most of them focus on explicit knowledge content only. This means that they mainly contain information that is “easily communicated, codified, or centralised using tools such as statistics” (GRANT ET AL., 2010), but they lack the kind of knowledge that “resides within individuals or a company, difficult to express in written forms” (LAM, 2000) (e.g. actors to be involved in the IS development process, success factors, barriers and approaches to overcome them). This second type of knowledge, also called tacit knowledge, is particularly important when dealing with IS implementation

process, as it allows to address contextualisation challenges (CHERTOW, 2004; DESROCHERS, 2004). Using tacit knowledge content such as information contained in the MAESTRI library of case studies, companies can understand which discovery processes have been successful and in which contexts, considering preconditions and stakeholders involved and therefore reducing biases due to individual perception. In addition, explicit and knowledge contents are both available and interconnected in MAESTRI tools, as the library and the database can be used jointly to have a complete overview of information available on a specific case.

The results of these activities have contributed to the foundation for the development of the toolkit within task 4.3 “Toolkit for industrial symbiosis (T4IS) with the four HOW TOs”.

1.2 What is the Toolkit for Industrial Symbiosis (T4IS)?

The T4IS is a set of tools and methods proposed to support companies developing IS applications. The different tools constitute a self-guided process that companies can use for identifying potentially exploitable wastes and value creation strategies.

The T4IS is framed in a very flexible way, aiming at providing support in multiple cases and contexts. It addresses both cases of inter-firm and intra-firm exchanges and supports the identification of one-off exchanges and continuous exchanges.

The toolkit builds on 4 guiding questions, which represents key 4 steps into generating an industrial symbiosis opportunity:

How to see waste concerns itself with how to be aware, recognise and discover wasted resources within the manufacturing process and facilities;

How to characterise waste relates to how to describe the character and properties of those identified wasted resources;

How to value waste concerns how to determine the estimated or assigned worth for the wasted materials;

How to exploit waste relates to how to utilise and make the best use of the wasted materials.

Table 1 summarises the list of proposed tools and methods for each step. An overview of the suggested tools is provided in section 3 of this Deliverable D4.3

Table 1 Overview of tools and methods proposed within the steps of the T4IS

T4IS step: How to....	See waste	Characterise waste	Value waste	Exploit waste
Primary tool/s	Value Uncaptured Analysis for production processes	MAESTRI Outputs Characterisation method: - Secondary outputs categorisation method - Additional operational and managerial information on secondary outputs	IS Exchange Opportunities Identification Analysis: - Market Analysis - MAESTRI Waste Exchanges Database - Organisation Network Analysis	IS Exchange Configuration analysis - IS exchange building template - Business Model Canvas
Complementary tool/s	Eco Orbit View (EOV); ecoPROSYS©; MSM©)	ecoPROSYS©	MAESTRI Library of case studies	MAESTRI Library of case studies; ecoPROSYS©
Secondary tool/s	Collaborative Treasure Hunts; Other tools using Value Stream Mapping	By-products Definition; Alternative Products/Waste classifications	Other IS related repositories and matchmaking tools	Blue Ocean Strategy; Quality Function Deployment (QFD)

1.3 What is the T4IS purpose?

The T4IS addresses the need for tools and methods to support self-organised IS. It represents a self-guided process that companies can use for identifying potentially exploitable wastes and value creation strategies. It is envisaged to need initially some facilitation and training from T4IS developers and afterwards companies will be able to use it themselves after the initial facilitation and training sessions.

The T4IS addresses key barriers to self-organised IS identified in Task 4.1 “Challenges and success factors for Industrial Symbiosis” and embeds the benefits of the tacit knowledge explored in Task 4.2 “Library of case studies and open source database of waste”.

The T4IS has the overall goal of changing the way how companies look at their waste, by considering that everything has potential to have or create value. Thus, the entire T4IS uses the term “waste resource” as an initial attempt to change companies’ perception of waste and support the mind-set shift towards seeing waste as a resource.

The waste hierarchy has been developed as part of the European waste policies and legislation, with the purpose of reducing environmental effects from waste and of improving resource efficiency in waste management and policy. This hierarchy offers a priority order for waste management by setting the best environmental options at the top (EUROPEAN COMMISSION, 2012).

Within this hierarchy, waste treatment refers to both operations for recovery and for disposal. Operations for recovery are separated into three categories in the waste hierarchy: Preparing for re-use, Recycling and Other recovery (e.g. energy recovery). As mentioned before, IS can occur within company boundaries (intra-firm) and outside company boundaries (inter-firm). Overall, being IS an approach to give an alternative use to waste resources as inputs for other manufacturing processes, the T4IS contributes to promote waste management activities at the higher ranking in the waste hierarchy, as necessary activities to enable the alternative use. In this line, it can derive a new activity for the hierarchy “Preparing for external use” to complement the “Preparing for re-use” and therefore, cover both cases of intra-firm IS and inter-firm IS.

The tacit knowledge and deeper research suggested in the T4IS bring further insights into how waste resources may need to be prepared for their external use by others. An overview of the waste hierarchy ranking and potential contribution of T4IS is shown in Figure 1.



Figure 1 Overview of waste hierarchy from IS exchanges perspective

1.4 Toolkit development process

The T4IS development process can be described in 4 iterative phases (Figure 2): exploration, conceptualisation, testing and refinement. The first two phases have been finalised while testing and refinement will continue during whole MAESTRI project to integrate new reflections and insights from the demonstration phase into the tools and methods. The main iterations, illustrated by central double-side arrows in Figure 2, occur between explorations and conceptualisation phases, and between testing and refinement phases.

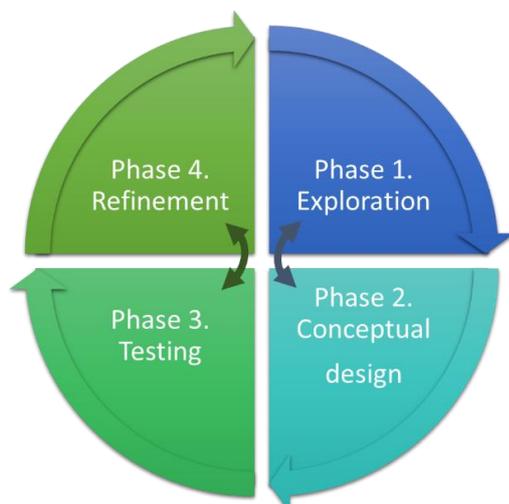


Figure 2 Toolkit development phases and main iterations

The exploration phase included the analysis of interactions with other tools and methods under development in MAESTRI, namely efficiency and eco-efficiency assessments and lean management tools. This phase focused on building the foundations for toolkit development with inputs from the set of exploratory interviews conducted in T4.1 “Challenges and success factors for Industrial Symbiosis” and from an extensive revision of the literature on supporting tools and methods for IS development. A full-day workshop was designed within this phase to evaluate the applicability of the value uncaptured concept to identify wasted resources at manufacturing process level and to analyse the necessary capabilities to develop IS and their possible synergies with eco-efficiency related capabilities. This workshop design and results are further described in subsection 1.4.1.

The conceptualisation phase built a draft design for T4IS tools and methods. Initial insights for the conceptualisation phase were obtained through the definition of desired outputs with regard to each toolkit guiding questions, including an analysis of necessary information to be obtained/gathered to achieve those outputs. This phase integrated findings from T4.2 “Library of case studies and open source database of waste” and from the workshop conducted within the exploratory phase. A full-day workshop was designed to gain more information on how the different HOW TO guiding questions could be connected with one another. This workshop is described in more details in section 1.4.2. Results from this workshop were used as inputs to the current design of T4IS tools and methods.

The testing phase includes discussions and partial testing of some constituent elements of the T4IS. The first workshop tested the conceptual approach for a novel application to How to see waste, while the second workshop tested the fit of results from previous T4.2 “Library of case studies and open source database of waste” as innovative tools and methods for waste characterisation and valorisation. A set of follow-up sessions with MAESTRI industrial partners tested a new waste classification proposal from their viewpoint. This classification proposal includes the use of two additional codes, apart from the EWC codes. The statistical classification of products by activity (CPA) and the Chemical Abstract Service (CAS) Registry Number®.

The CPA is a European classification that identifies all products produced by each production activity (mining, farming, forestry activities, manufacturing processes, service provision, etc.). Production activities are represented by the first two of the six digits of the product code and identified according to the NACE classification (EUROPEAN COMMISSION, 2008).

The CAS Registry Number® (CAS Number) is an index of chemical substances developed by the American Chemical Society (CAS.ORG, 2017). It is used worldwide to univocally identify chemical substances, and generally applied in industrial firms to purchase procedures. The CAS Number is a numeric identifier composed of up to ten digits and assigned to a chemical substance (element or molecule). It has no chemical significance, but in contrast with other chemical identifiers, usually non-numerical, it is easier to use (CAS.ORG, 2017). The American Chemical Society has launched in 2009 a free web-based resource ("Common Chemistry™")¹ containing the CAS Numbers of all chemical elements and most common chemical substances.

In order to initially test this classification, data on value uncaptured from initial workshops was confronted to data gathered from companies on EWC codes for the usability test performed within T4.2 "Library of case studies and open source database of waste". The identified value uncaptured was listed and matched to EWC codes provided previously by the companies by using descriptions of waste given and additional web-based open source tools (such as wastesupport.co.uk). Finally, CPA codes and CAS Numbers were associated to each waste resource, where applicable. Results were discussed with industrial partners afterwards.

The refinement phase run in parallel to the testing phase and concerns changes in the T4IS design to improve usability and relevance of results. Refinements related to testing the first version of the T4IS have been integrated into the version included in this Deliverable D4.3.

1.4.1 Initial workshop for toolkit development

This workshop was developed with a two-fold objective: to start early conversations on IS possibilities in MAESTRI pilot cases and to obtain information on usefulness of the concepts / tools under development. It was created as a full-day activity encompassing two independent workshop sessions.

Session on uncaptured value analysis. This first workshop session aimed at identifying sustainable value improvement opportunities at manufacturing process level. The session is based on a method developed at University of Cambridge to unlock value opportunities for companies (EVANS ET AL., 2013). The method brings new perspectives on value captured, missed and destroyed occurring in manufacturing processes and a structured way to discover potential new uses of value that is currently uncaptured by the company and its stakeholders. This analysis contributes to identifying wasted resources and their reuse potential.

Session on capabilities for industrial symbiosis aims at identifying capabilities acquired and required to support the implementation of IS. Additionally, it will enable a comparison with capabilities necessary for eco-efficiency improvements. A template poster to facilitate

¹ <http://www.commonchemistry.org/>

discussions during the workshop was developed for this session (Figure 3) to lead the analysis on capabilities acquired and required and to set some future targets for the implementation of eco-efficiency practices and the potential application of an IS approach.

Current Stage		Future stage		
① Eco-efficiency Current practice	Acquired Capability	Required Capability	③ Eco-efficiency future Target	Challenge
② Industrial symbiosis Current practice	Acquired Capability	Required Capability	④ Industrial symbiosis future Target	Challenge

Figure 3 Template for the capabilities analysis

This initial workshop for toolkit development was conducted with three MAESTRI industrial partners individually in February and March 2017. Results from this workshop suggested that the value uncaptured method was useful to identify wasted resources. Participants' feedback confirmed the usefulness of the workshop as a means to structure and give solid scientific basis to waste identification activities, successfully informing decision making and to create action plans for the companies.

The capabilities analysis brought interesting results in terms of necessary capabilities for IS development. A summary of the identified capabilities is given in Table 2. It is worth to note that most capabilities would have an effect in the whole implementation process, such as compliance with legislation or integrated management team. Other capabilities were identified with a specific contribution to one or two toolkit steps, as indicated in the table.

Table 2 Key capabilities for IS identified in the capabilities analysis session

T4IS steps	Acquired capability	Required capability
General	<ol style="list-style-type: none"> Having dedicated integrate management system team Knowledge on waste management (based on waste classification) Ability to comply with certifications (good waste management practices) 	<ol style="list-style-type: none"> Having dedicated team for specific waste streams (to increase understanding processing steps to add value of waste) Cross-functional knowledge. More resources required Better time management
How to see waste; How to characterise waste	<ol style="list-style-type: none"> Synergies between teams inside company to help each other, such as sharing knowledge more specifically in more areas and have more communication with people from shop floor Classification of waste done by the quality team 	<ol style="list-style-type: none"> Employee engagement for IS (awareness, idea generation, information collection)

T4IS steps	Acquired capability	Required capability
How to value waste; How to exploit waste	6. Ability to understand internal reuse options 7. Understand which waste is possible to commercialize with 8. Understanding their clients needs in terms of resources 9. Test technical feasibility of solutions in the shop floor before implementation	5. Employee engagement for IS (awareness, idea generation, information collection) 6. Creating networks in anticipation of new waste streams 7. Ability to replicate good sales team for waste streams

1.4.2 Second workshop for toolkit development

This workshop was framed within the MPhil dissertation work of Merane Dubois. She collaborated in the MAESTRI project during her dissertation by performing an in-depth study on how companies can find possible buyers for their waste resources. The testing of some MAESTRI tools and methods was integrated into the workshop agenda, in order to give an adequate workflow and do not use them as stand-alone. The workshop agenda included sessions on the identification and classification of waste, the identification and evaluation of potential uses, the analysis and prioritisation of potential buyers and the development of a value proposition adapted to the buyer profile.

This workshop enabled to complete a series of follow-up sessions with MAESTRI industrial partners regarding the results obtained from the library of case studies and waste database.

During such follow up sessions and the final one-day workshop, companies have been asked to express their opinion regarding: (1) the potential feasibility and next steps of the main findings obtained from the usability test of the library and the database; (2) the classifications used to categorise their waste resources.

Feedback on library/database findings

All of the companies have had internal follow-ups regarding the library and database usability test results. Main actors involved in these follow-ups were: production managers, subcontractors dealing with waste management, quality managers, and environmental and energy managers.

Most of the identified potential exchanges (18 flows in total, with different companies identified as potential receivers) are considered relevant for the companies, while three of them are not due to contextual factors. Results are detailed in Table 3.

Table 3 Summary relevance of results from library / database

Results from library/database for MAESTRI industrial partners		Additional remarks
Identified exchanges considered as relevant by industrial partners	15	2 exchanges are considered relevant but not feasible due to product quality issues (based on feasibility studies performed in the past)
		1 exchange is already implemented internally
		9 exchanges related to waste packaging need to be further studied (packaging is currently correctly disposed but companies are interested in finding an alternative, more

Results from library/database for MAESTRI industrial partners		Additional remarks
		profitable solution); due to low volumes produced, this is usually not a priority
		3 exchanges related to non-packaging materials need to be further studied
<i>Identified exchanges considered as non-relevant by industrial partners</i>	3	The non-relevance is due to contextual factors (e.g. different air temperature conditions compared to similar companies operating in different countries, parts of production processes subcontracted)

The main aspects to be considered for feasibility studies of identified exchanges are:

- Verify the amount of volume available for the waste resource;
- Discuss potential product quality issues with existing / potential customers;
- Try cold contacts with potential partners or use existing clusters/networks to start discussions, especially at management level;
- Perform deeper technical studies: process specifications, legal and logistic issues.

Feedback on classification systems

All of the companies reported that they are already familiar with classification systems used to identify waste resources and by-products (EWC and CPA codes), and in particular they all use EWC codes for regulatory compliance. Two of them also already know CAS Numbers. The familiarity with these classifications is seen as a positive factor for tool implementation, as this would entail a reduced amount of resources needed to perform this activity.

One company highlighted the fact that using international classification could help also starting conversations with companies from other countries, while another company suggested that indicating tools to translate national classifications into international classifications could be helpful.

Three of the four companies highlighted the need of considering a classification that is more specific than EWC or CPA codes. CAS Numbers are considered a suitable solution to this purpose. Nevertheless, data should be carefully gathered regarding the form in which each substance is actually available and the possibility to separate it from the others.

2 How to use the toolkit for industrial symbiosis?

The T4IS is available as a set of workshops facilitated by the MAESTRI team at University of Cambridge. After a first facilitated use of the T4IS, companies should be able to conduct the process on their own. Thus, empowering them to advance at their own path towards a wider application of IS in their business operations.

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Table 4 provides an overview of some key parameters for the use of the T4IS: application timeline, application scope, key information needed as input for the step and key participants to involve in the different steps.

Table 4 Overview of how to use the T4IS

T4IS step: How to....	See waste	Characterise waste	Value waste	Exploit waste
Application timeline	1-2 weeks	2-3 months	4-6 months	2-3 months
Application scope	Broad scope	Broad scope	Broad & Individual scope	Individual scope
Key information needed	Inputs and outputs materials / energy / water from production processes and possible losses or leakages of materials / energy / water	Quantity and characteristics of each material included in waste streams; For hazardous waste, what type of hazard, what safety, treatment is needed	Waste characterised as per previous step; For selected waste resources, what are the stakeholders and their interest / stake on the resource	Industries located in the local/ regional area, their main production activities, and when possible, the main inputs and outputs of their production processes
Key participants to involve need to cover the following responsibilities	Plant management, energy and resources efficiency practices, production line operations.	Plant management, energy and resources efficiency practices, environmental analysis, production line operations.	Business and plant management, energy and resources efficiency practices, production line operations, purchasing and sales operations.	Business and plant management, energy and resources efficiency practices, purchasing and sales operations.

The application timeline gives an initial idea of the time to be dedicated for preparation and information gathering activities as well as the actual workshop session and necessary follow-ups after the workshop. Follow-ups will cover mainly additional information to gather and actions to be taken as result of the identified opportunities.

The application scope indicates whether the T4IS step covers a single resource or a group of resources. The T4IS begins by considering a set of waste resources identified with the value uncaptured analysis, the number of resources under consideration decreases as steps are advancing. The most promising waste resources and their potential uses will be selected along the process. The last step is meant to be performed for one individual resource at each time. Figure 4 illustrates how the application scope narrows down as selection decisions are taken between phases (D1, D2, D3 in the figure).

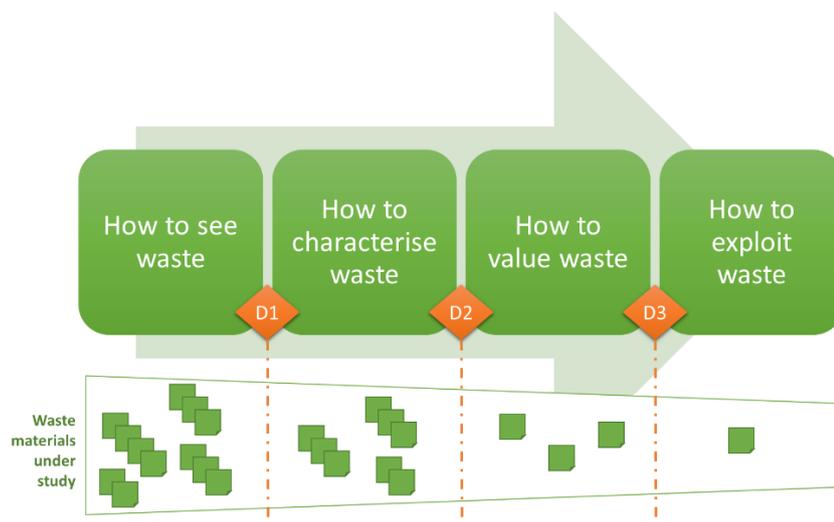


Figure 4 Application scope of the T4IS

3 Toolkit description

This section describes the different steps within the T4IS, providing details on the primary tools and methods to be used and a brief description of the complementary and secondary tools and methods. References are provided for further consultation on them, if necessary.

3.1 How to see waste

This step aims at creating a comprehensive list of resources within production processes and facilities that can be subject to potential Industrial Symbiosis applications, such as waste streams, by-products and input resources.

The proposed method is based on previous work developed by the Centre for Industrial Sustainability at the University of Cambridge. The method had been applied to the identification of business model innovation (Rana et al., 2017; Bocken et al., 2013) and product life cycle innovation (Yang et al., 2014) opportunities for sustainability. Within MAESTRI, the method has been applied at manufacturing process level, which constitutes a new application. An overview of the method and the steps for its application within MAESTRI scope is given next.

This step has many synergies with other MAESTRI tools that will be explain therein. Besides, some alternative tools are additionally suggested, for cases in which companies would like to use multiple tools and methods to supplement / compare results at this step.

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3.1.1 How to see waste - Primary tool

Value uncaptured analysis for manufacturing processes

Description

This analysis is built on the basis of a value mapping exercise proposed by Evans et al. (2013) for the Value Mapping Tool, within a sustainable business modelling process. Within MAESTRI,

this mapping exercise is proposed and tested for its use at factory level, thus, applied to individual manufacturing processes rather than companies as a whole.

This systematic assessment of value is “based on the observation that business model innovation for sustainability not only needs to seek to create new forms of value, but must also seek to address value that is currently destroyed or missed” (Rana et al., 2017). This systematic assessment has been used as foundation for further research within the Centre for Industrial Sustainability. For example, Yang et al. (2014; 2017) extended the use of this assessment to the whole product life cycle perspective. This work introduced the concept of value uncaptured as helpful to identify areas requiring change or improvement along different life cycle stages. This extension included also the production phase at manufacturing companies but limited insights have been obtained in this regard so far.

Based on the premise that value destroyed and missed can be also found at production processes, this analysis is proposed as preferred method for the How to see waste step within the T4IS. The concepts of value captured, value destroyed, value missed, and value opportunity are defined as follows for this analysis at production level:

- **Value captured** refers to the set of benefits currently delivered to different stakeholders from the production processes. It considers economic, environmental and social value aspects, e.g. high product quality, use of low emissions processes.
- **Value destroyed** refers to negative outcomes of current production processes, e.g. waste generation, unnecessary energy consumed.
- **Value missed** refers to positive outcomes created and not delivered or inadequately captured or being lost / underutilised, e.g. unused high temperature generated, unused capacity, ineffective buffer times management.
- **Value opportunity** refer to a new activity, process, relationship or initiative to create additional benefits to eliminate value destroyed and / or recover value missed, e.g. reallocate resources in a certain manner, create improvement mechanisms / protocols.

This analysis provides a structured approach for the assessment of value uncaptured and uses this concept to uncover new value opportunities.

How to use the tool

The process begins by identifying a product to focus the analysis on. This will help to define the boundaries of the area within the manufacturing facilities to consider within the scope. Once this is agreed between participants, the following steps are performed:

1. Create a map of the manufacturing processes for the product selected, including inputs and outputs at each production stage;
2. Identify the main stakeholders of manufacturing processes
3. Identify the value uncaptured in each manufacturing process
 - What are the negative outcomes?
 - Are there underutilised resources in the processes? Are there excessive outputs larger than the requirements?
4. Identify value opportunities:

- Identify ways to eliminate value destroyed – e.g. reducing the negative impact, turning it into positive value
 - Identify ways to utilise value missed – e.g. reusing manufacturing outcomes, using under-utilised capabilities
5. Assess the value opportunities identified. A simple visual two-axis approach is proposed to map the value opportunities against perceived feasibility and perceived positive impact. This step will allow brainstorming among participants.

3.1.2 How to see waste - Other tools

How to see waste - Complementary tools

Eco Orbit View (EOV) > is a method to identify and prioritise areas in the production process that could be analysed and modified to achieve business and environmental performance improvements with the same operations-oriented improvement activities (synergy effect). It is based on the definition of key performance indicators to enable the identification of improvement opportunities. Further description of this tool can be found in MAESTRI D3.2 "Management System Framework for Continuous Improvement in Process Industries" (MAŚLUSZCZAK ET AL., 2017). The very first step to implement such method is to identify and map production process' steps, generating a deeper and more complete knowledge of the process itself. Thus, it seems that running an EOV workshop before conducting the value uncaptured analysis helps reach the desired level of knowledge of the production process.

Eco-Efficiency Integrated Methodology for Production Systems (ecoPROSYS©)> is an approach to environmental performance evaluation based on the use of a systematized and organized set of indicators. Its main purpose is to help companies continuously improving their efficiency in resources and energy use. It is a valid support in the assessment of eco-efficiency performance and in related decision-making activities. Further description of this tool can be found in MAESTRI D2.3 "Simulation and decision support approach for sustainable manufacturing" (SILVA ET AL., 2016). It could support the value uncaptured analysis to identify production residues, their origin and quantity.

Multi-Layer Stream Mapping (MSM©) > consists of a method / tool designed to assess the overall efficiency of a production system. It has been developed on the basis of the Value Stream Mapping (VSM) tool, already in use in Lean management. Its main purpose is to support companies identifying and quantifying all "value adding" and "non-value adding" actions and all types of waste and inefficiencies of their production systems. Further description of this tool can be found in MAESTRI D2.3 "Simulation and decision support approach for sustainable manufacturing" (SILVA ET AL., 2016). It could complement the value uncaptured analysis to identify and quantify process waste, as well as different originating processes.

How to see waste - Secondary tools

Collaborative Treasure Hunts (Next Manufacturing Revolution, 2014)

Inspired by activities done by GE, the collaborative treasure hunts bring experts from different plants and outside of the company together to look for improvement opportunities in one plant, in terms of equipment, processes, systems and staff behaviour. These treasure hunts allow also knowledge transfer and good practices sharing. More information can be found here: <http://www.nextmanufacturingrevolution.org/new-resource-efficiency-tool-collaborative-treasure-hunts/>

Other tools using Value Stream Mapping for sustainability management

Several authors have proposed different applications of the Value Stream Mapping tool used in Lean management to sustainability, aimed at helping companies identify and visualise their waste (including material, water, energy, waste). Some of these tools are for example:

- The Environmental Value Stream Mapping (SILVEIRA TORRES and GATI, 2009). It is a tool designed for top and middle management to help them aligning the economic and environmental view of the production process. By creating a first map of the main flows (of product/materials, water, energy) in the process and balancing them across the process it allows to map waste and identify improvement opportunities.
- The Sustainable Value Stream Mapping (FAULKNER and BADURDEEN, 2014). It is a tools designed to integrate both environmental and societal impacts and waste to the traditional VSM. It identifies a series of metrics to evaluate economic, environmental and societal impacts in the whole process and therefore individuate potential improvements
- The Economic and environmental value stream map simulation (ALVANDI ET AL., 2015). This is a methodology to model material, energy and information flows within a manufacturing process, and with a specific focus on multi-product processes. It uses various input data available from information systems and other metering systems to map the process and inform decisions regarding waste and losses.

3.2 How to characterise waste

This step pursues the characterisation of all previously listed resources that can be subject to Industrial Symbiosis applications, including information regarding volume and frequency of generation, inherent chemical and physical characteristics, substitutability or replacement potential, hazardous behaviour and mitigation and neutralisation actions.

This proposed characterisation method consist on a set of suggested activities to gather deeper information in a systematic way about the outputs of the manufacturing processes under study. Figure 5 gives an overview of these activities and information to be gathered.

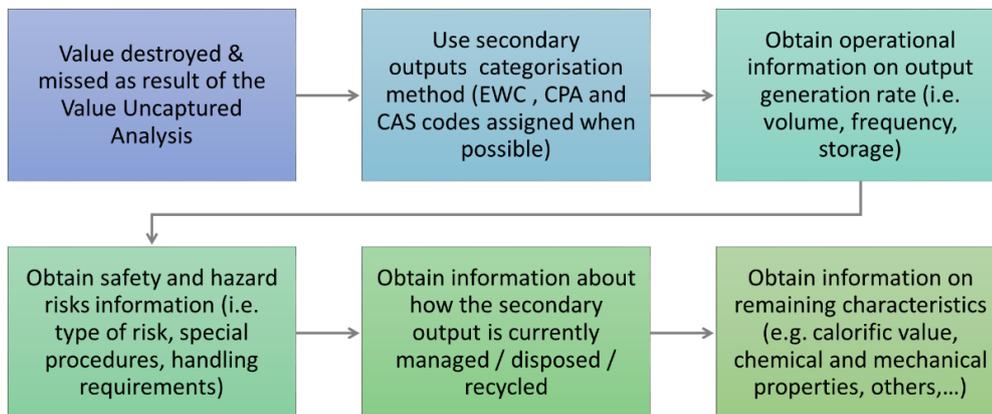


Figure 5 Overview of activities to characterize secondary outputs

The basis for this characterisation is given by a proposed categorisation of secondary outputs that allows to univocally identify them and to keep an organised record, as well as to gather initial information related to their chemical composition when possible. This categorisation is complemented with operational data to fully understand their nature and remaining properties.

The categorisation of secondary outputs is the result of exploratory discussions among MAESTRI partners for alignment between WP2 “Efficiency Framework” and WP4 “Industrial Symbiosis” activities during a field session in July 2016 and of emerging findings from the development of the library and database within T4.2 “Library of case studies and open source database of waste”. The final version has been further refined basing on additional inputs from follow-ups with MAESTRI industrial partners, from literature (CECELJA ET AL., 2015; AID ET AL., 2015) and other projects’ outputs (e.g. IS DATA website²).

The proposed categorisation (see Figure 6 **Error! Reference source not found.**) combines three existing classifications of products and waste that are already well known and widely implemented at a European level. This allows an easy implementation for companies, which are usually already familiar with such classifications’ structure and codes.

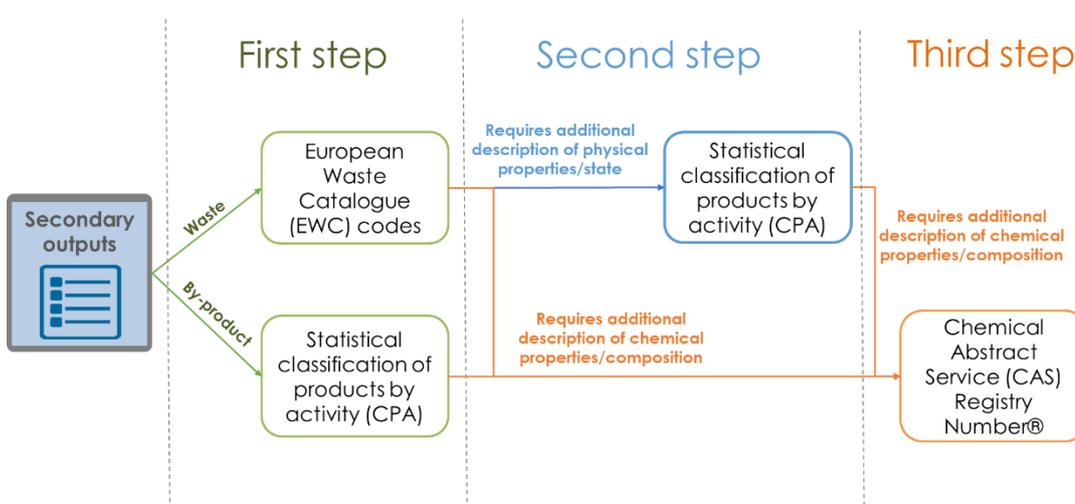


Figure 6 Proposed categorisation for secondary outputs of production processes

² <http://isdata.org/>

3.2.1 How to characterise waste - Primary tool

MAESTRI Outputs Characterisation method

Description

The secondary outputs categorisation method is based on three existing and widely implemented resources classifications: EWC, CPA and CAS Registry Number®, introduced in previous sections.

EWC codes are used to identify waste and to enable communication between companies producing waste and companies managing and disposing waste. The EWC does not include resources not classified as waste (e.g. by-products, as per (EUROPEAN COMMISSION, 2007)), provides in some cases a description of the waste in too general terms and does not allow to examine in deeper details the composition of waste resources that come as bundles of different substances. To overcome this issues, CPA codes and CAS Numbers are suggested to complement EWC when possible.

The CPA includes all products and by-products generated by industrial facilities (including energy, heat and water), but, as for the EWC, which presents a similar structure, does not allow to examine in deeper details the chemical composition of resources. In this regard, CAS Numbers can be helpful as they allow to univocally identify the chemical components within products and by-products.

Within the categorisation method, EWC and CPA codes are generally used to define waste and by-products respectively. CAS Numbers are used in addition to identify main chemical components of both resources and by-products.

As regards waste resources though, it can sometimes happen that the EWC code alone is not sufficient to categorise the material in a way that enables further analyses on potential uses. For example, describing waste paper bags using the EWC for paper and cardboard packaging is restrictive in two ways: first, the EWC code does not give any information regarding the type of packaging considered (sacks, boxes, etc.), and second, they might also be considered not as paper bags but as source of non-impregnated paper or as pulp for new paper production (see following Table 5). Thus:

- a) The EWC codes give too general information regarding physical characteristics of the material.
- b) The user is aware that the material considered can be subdivided or transformed by the means of mechanical (i.e. non chemical) treatments into parts that are still reusable.

It could be useful to associate corresponding CPA codes to the EWC code of the material. In practice, associating a CPA code to a material that is already classified by a EWC code allows to conduct deeper analyses on its physical characteristics in the same way as associating a CPA Number allows to conduct deeper analyses on its chemical characteristics.

Table 5 Example of EWC, CPA and CASRN(R) associated to a waste resource

EWC		CPA		CAS Number	
15 01 01	paper and cardboard packaging	17.21.12	Sacks and bags of paper	9004-34-6 ³	Cellulose
		17.12.71	Composite paper and paperboard, not surface-coated or impregnated		
		17.11.13	Chemical wood pulp, sulphite, other than dissolving grades		

The different sets of operational and managerial information are proposed as a result of discussions and observations during visits, workshops and meetings regarding characterisation needs to uncover value in secondary outputs. The steps to gather this information are provided below.

How to use the tool

The process starts by listing all value destroyed and missed related to resources obtained during the value uncaptured analysis. Then, the following steps are performed for each of those waste resources:

1. Use the secondary outputs categorisation method to obtain EWC, CPA and CAS codes when possible. The subsequent activities to perform this method are:
 - Associate EWC codes to waste resources and CPA codes to by-products, considering the process where they were generated as per classifications lists;
 - Follow the decision tree (Figure 7) for selecting further classifications;
 - Conduct a composition analysis when needed to assign CAS Numbers to those waste resources subject to this classification.
2. Obtain operational information on outputs generation rate such as
 - How much is generated (volume per unit of time, e.g. hour, month, year...);
 - How often is generated? (one off; during changeovers; continuously);
 - How the storage system (space capacity and logistics) is currently organised?
3. Obtain safety and hazard risks information (i.e. type of risk, special procedures, handling requirements)
4. Obtain information about how the secondary output is currently managed / disposed / recycled and the costs related to the activities
5. Obtain information on remaining characteristics (e.g. calorific value, chemical and mechanical properties, others...)

Decision tree for classifications selection

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After a first differentiation of secondary outputs in waste (EWC codes can be assigned) and by-products (CPA codes can be assigned), it is suggested to further analyse both types of resources and to associate additional codes by following steps identified in the decision tree represented in next Figure 7.

³ <http://www.commonchemistry.org/ChemicalDetail.aspx?ref=9004-34-6&terms=cellulose>

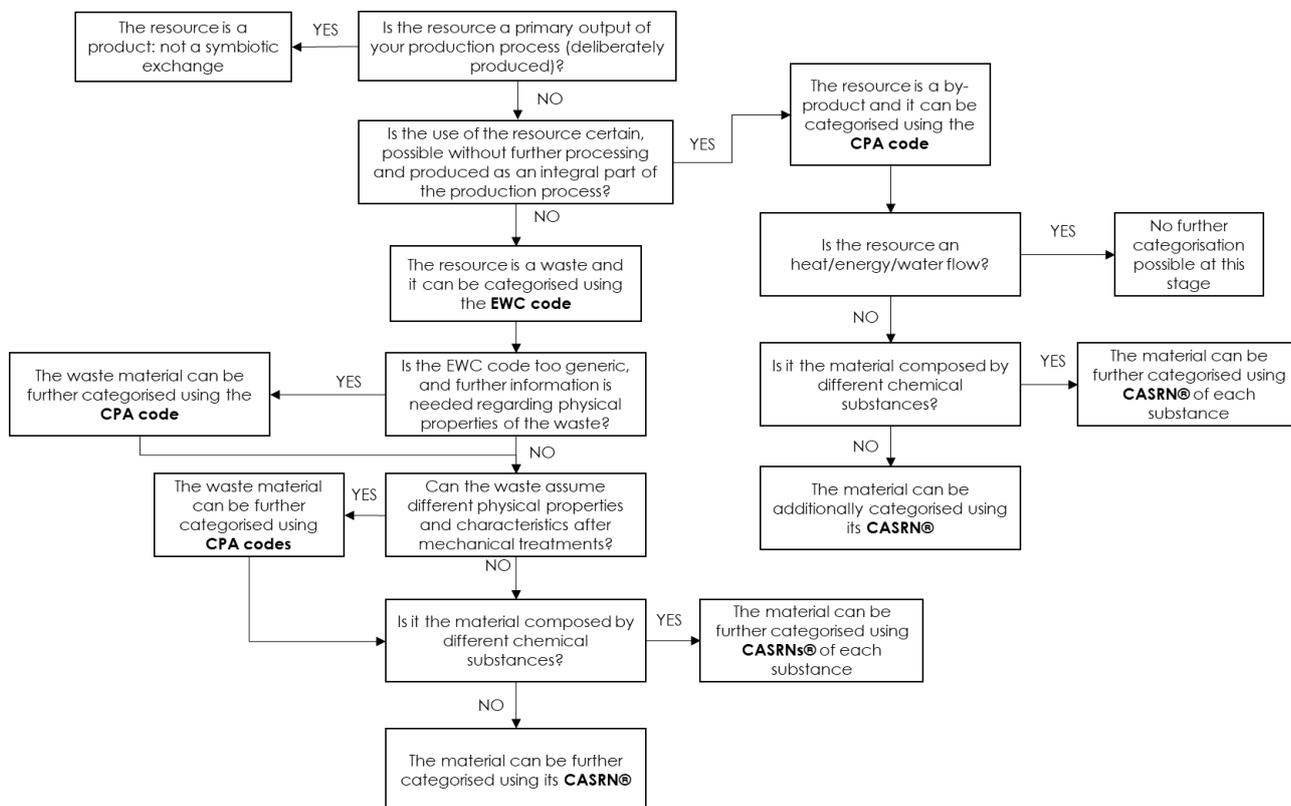


Figure 7 Decision tree for classification selection

The starting point of the decision tree is to categorise the secondary output of the process as a waste or as a by-product (first two steps of the decision tree). This decision is guided on the basis of what stated in (EUROPEAN COMMISSION, 2007).

If the output is categorised as waste, an EWC code can be associated. After the identification of the EWC as main classification for the output, three consecutive questions guide the user to assess the need for further categorisation of the output (either CPA or CAS Number/Numbers).

If the output is categorised as by-product, a CPA code can be associated. After the identification of the CPA as main classification for the output, two consecutive questions guide the user to assess the need/possibility of associating one or several CAS Numbers to the output. The association is not possible if the output considered is a heat/energy/water flow.

Taking always waste paper bags as an example (see Table 2):

- They are not a primary output of the production process;
- Their use is not certain, is possible without further processing and they are not produced as an integral part of the production process;
- They can be categorised as waste and associated to the EWC code “15 01 01: paper and cardboard packaging”;
- The EWC code is too generic, as it does not make any reference to the shape of the packaging (it could be boxes, sacks, bags, etc.), thus the waste can be further categorised using the CPA code “17.21.12: sacks and bags of paper”;
- The waste can assume different physical properties and characteristics after mechanical treatments (e.g. bags can be “opened” to obtain paper foils or

mangled to obtain pulp), thus the waste can be further categorised using the CPA codes “17.12.71: composite paper and paperboard, not surface-coated or impregnated” and “17.11.13: Chemical wood pulp, sulphite, other than dissolving grades”;

- The waste is not composed by different chemical substances, but by one main substance, thus it can be further categorised using the CASRN® “9004-34-6: Cellulose”⁴.

Web tools to support codes identification

In order to facilitate the association of codes to the secondary outputs, mainly based on the comparison of the waste description with the description associated to each code in the proposed classification, and the consequent selection of the most suitable, it is possible to use some open access web tools. In particular, the following tools are suggested:

- ISDATA search⁵: it is a search facility developed by TU Delft that allows to match EWC codes to a general short description of the waste. It also has a “fuzzy search” functionality that support more refined searches.
- Wastesupport.co.uk⁶: it is a search facility that takes waste materials' descriptions and common names as input and gives best matching EWC codes as output. It has been developed by the Environmental Agency in collaboration with Thesaurus.
- CommonChemistry™⁷: it is a free tool developed by the Chemical Abstracts Service in collaboration with WikiPedia. It allows to pair names and CAS Numbers of most common chemical substances.
- PubChem⁸: it is an open access web database of chemical substances, searchable by CAS Number, name of the substance, EC Number, InChI and others. It allows to translate different classifications for chemical substances and also to retrieve information regarding chemical and physical properties, industrial users and producers of each substance.

3.2.2 How to characterise waste - Other tools

How to characterise waste - Complementary tools

Eco-Efficiency Integrated Methodology for Production Systems (ecoPROSYS®) is an approach to environmental performance evaluation based on the use of a systematized and organized set of indicators. Its main purpose is to help companies continuously improving their efficiency in resources and energy use. It is a valid support in the assessment of eco-efficiency performance and in related decision-making activities. Further description of this tool can be found in MAESTRI D2.3 “Simulation and decision support approach for sustainable manufacturing” (SILVA ET AL., 2016). ecoPROSYS® includes a Life Cycle Assessment (LCA) methodology to identify, quantify and assess the environmental aspects of product systems. The application of the LCA databases within ecoPROSYS® can support

⁴ <http://www.commonchemistry.org/ChemicalDetail.aspx?ref=9004-34-6&terms=cellulose>

⁵ <http://enipedia.tudelft.nl/ISDATAsearch.html>

⁶ <http://www.wastesupport.co.uk/ewc-codes/>

⁷ <http://www.commonchemistry.org/>

⁸ <https://pubchem.ncbi.nlm.nih.gov/>

this step. LCA-based methods use both CPA and CAS Numbers, therefore, this allows the alignment with the How to characterise waste step.

CPA product categories are used for coding and defining the information modules used to represent the product life cycle. CAS Numbers are also used in many Life Cycle Analysis software and tools to identify different chemical substances, as the CAS Registry also allows retrieving additional information on each substance.

Focused gemba walk/ Retrospective analysis > Focused Gemba Walk is a method based on direct observation of a potential improvement area identified during an Eco Orbit View analysis. Retrospective analysis is a method to find root causes of a problem without the need for an extensive data collection over a long period. Further description of these tools can be found in MAESTRI D3.2 "Management System Framework for Continuous Improvement in Process Industries" (MAŚLUSZCZAK ET AL., 2017). Both tools could be helpful to obtain operational information on output waste generation and to obtain information regarding how the secondary output is currently managed. Use of these tools would bring the spirit of root cause analysis and possibly improve the quality of information gathered.

How to characterise waste - Secondary tools

By-products Definition (EUROPEAN COMMISSION, 2007)

The European Commission has proposed a decision tree to distinguish between waste and by-products, in its by-products definition communication in Annex II. The decision tree is illustrated in Figure 8.

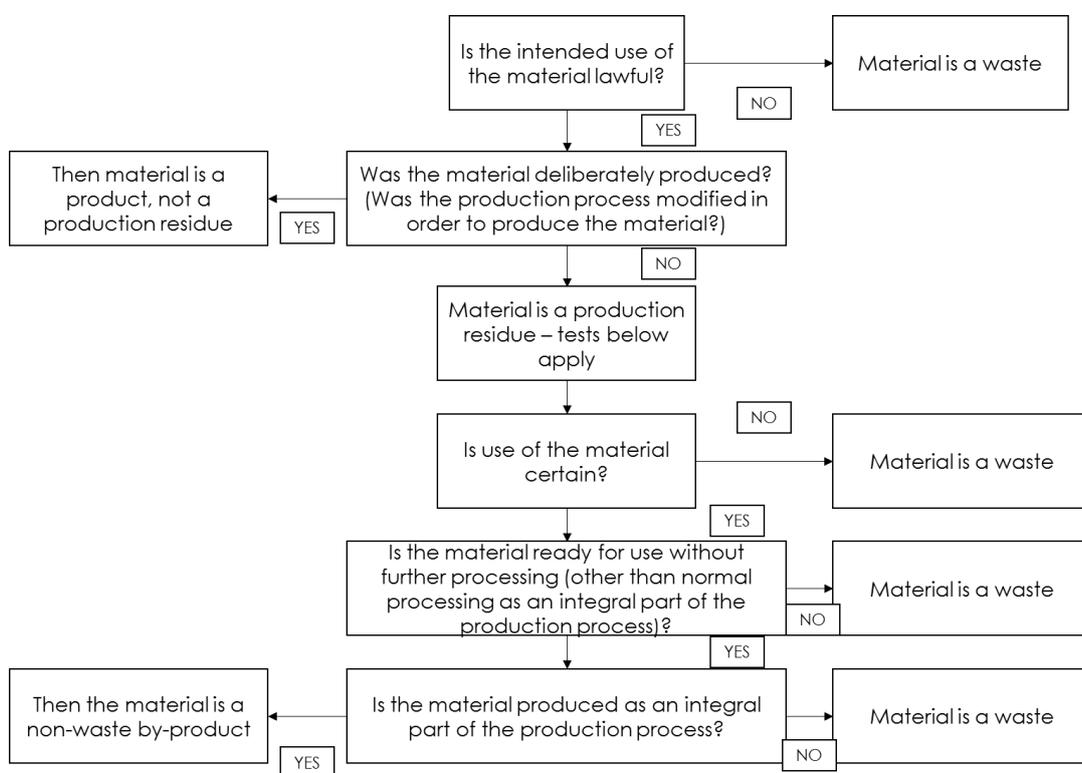


Figure 8 Decision tree for by-product definition (adapted from EC, 2007)

Additionally, alternative classifications can be suggested in case companies would like to customise the categorisation according to their specific needs.

Alternative Products/Waste classifications

NAPCS⁹: the North American Product Classification System (NAPCS) is the products and services classification diffused in North America. Its hierarchical structure is similar to the CPA classification, but it is less linked to the production process and more linked to the market demand.

InChI¹⁰: the IUPAC International Chemical Identifier univocally identifies chemical substances by the means of a text string. Such text string reflects the molecular structure of the substance thus already includes information on chemical properties. It is developed by the International Union of Pure and Applied Chemistry (IUPAC).

EC Number¹¹: the European Community Number is a seven-digit identifier assigned by the European Chemicals Agency (ECHA) for regulatory purposes. It has a structure similar to the CAS Number but it is less used.

3.3 How to value waste

This step addresses the search for potential exchanges and further analysis, such as experiments, in-depth research or definition of knowledge gaps, required to better understand the value opportunities. These knowledge gaps will frequently be related to necessary or required treatment processes, materials separation or extraction methods, remaining value in terms of physical / chemical properties, etc. This step takes into account the potential stakeholders for the value opportunities.

The analyses proposed for this step are built on some results of the MPhil Dissertation of Merane Dubois obtained during a full-day workshop described in 1.4.2, aimed at testing their reliability and validity within the MAESTRI project. The key outcomes in this regard are the following:

- Understanding the market value of waste resources and their constituent substances, when defined, is regarded as fundamental to assess whether to devote additional efforts to waste valorisation;
- Using their own company's network (known companies already contacted in the past) to consult on specific waste resources activities seems to be a straightforward action. This will be used to seek information on solutions that others, from same supply chain or within managerial/ sectorial networks, are using to address same waste resources and to initiate collaborations to address bigger challenges together.
- Analysing the potential market for their waste resources as if it was for new products is necessary. It enables to make the company see the valuable benefit from their waste and target the most relevant markets while gradually embedding this new culture to the company.

⁹ <https://www.census.gov/eos/www/napcs/>

¹⁰ <https://www.iupac.org/home/publications/e-resources/inchi.html>

¹¹ <https://echa.europa.eu/it/information-on-chemicals/ec-inventory>

The use of repositories as sources of ideas for potentially feasible exchanges has been also tested through the series of follow-up sessions on the waste exchanges database explained in 1.4. As mentioned, most of the identified potential exchanges (18 flows in total, with different companies identified as potential receivers) were considered relevant. This confirms the adequacy of using the waste exchanges database at this step to value waste.

It is possible to run this step for one single waste resource or for several at the same time. Experience in workshops suggest that it is better to focus on one type of waste or a small group of closely related wastes, in order not to bring too many insights into the brainstorming discussion at the same time.

3.3.1 How to value waste - Primary tool

IS exchange opportunities identification analysis

Description

This analysis consists on the use of three sources of information to identify possible exchanges for the waste resources and the potential value of those exchanges. An overview of these sources and the objectives of using them are shown in Figure 9.

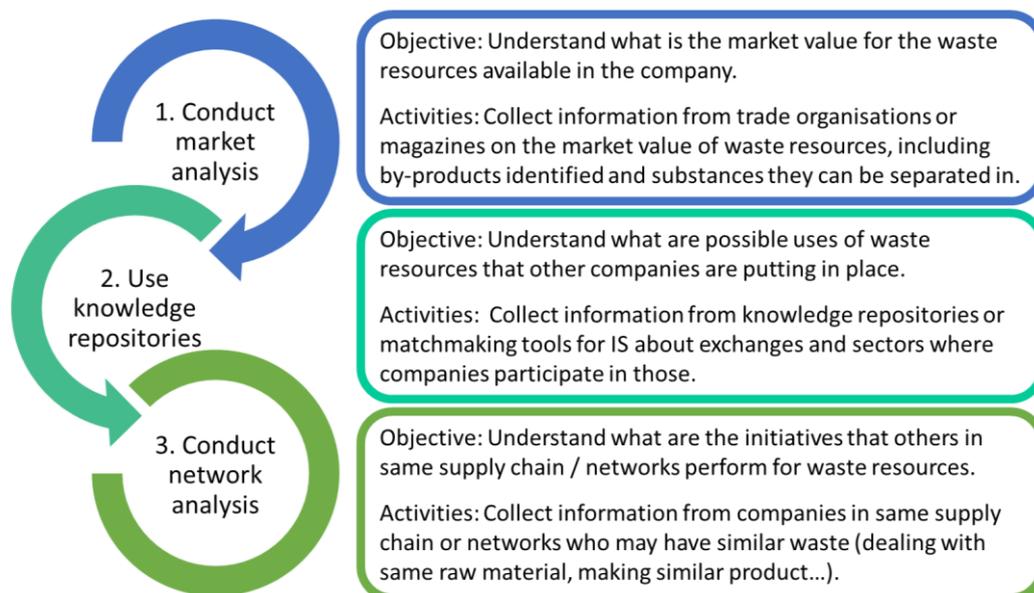


Figure 9 Overview of sources of information to identify IS exchanges

These three sources provide certain information and, at the same time, support the identification of knowledge gaps in relation to possible uses of the waste resources. The identification of knowledge gaps highlights the aspects that need deeper research to fully understand the value opportunities. This identification of deeper research to be conducted is another important outcome of this analysis.

Regarding knowledge repositories, the selected tool is the MAESTRI Waste Exchanges Database. This database contains the description of 426 symbiotic exchanges, detailing information regarding companies involved (NACE codes and sectors), the exchanged resource (brief description, EWC code when available, treatment needed) and the final

use given to that resource. Other knowledge repositories and matchmaking tools that can be used instead are introduced later in 3.3.2.

How to use the tool

The process starts with the list of characterised waste resources from the previous steps. A pre-selection of those waste resources needs to be done on the basis of each company business context to focus the study on the most relevant ones. Criteria to be considered could be the perceived value to be gained (according to the perception of the market), perceived easiness to find a potential reuse (according if more or less experiments are thought to be necessary, to previous guessed or heard application etc.) and the disposal cost (which was identified as the most motivating reason).

After that, the following steps need to be done for the selected waste resources:

1. Conduct the Market Analysis to understand the market value of those resources. Market value is related to both resource / substance demand, based on scarcity / availability levels, and resource / substance market price. An example of a source to gather this information are trade magazines such as Materials Recycling World (<https://www.mrw.co.uk/>)¹².
2. Use the MAESTRI Waste Exchanges Database by performing the two standard queries defined in Deliverable D4.2 "Prototype library of case studies linked to a waste database" and summarised in 1.1: (A) looking for similar companies and; (B) looking for exchanges of similar waste materials (BENEDETTI ET AL., 2017).
3. Conduct the Organisation Network Analysis to understand what are the type of companies in your network (i.e. same supply chain, managerial / sectorial networks, neighbours, ...) who may have similar waste (dealing with same raw material, making similar product...), or a complementary waste (waste that combined to yours could create a solution) or may be interested in your waste.

To capture the results of the information searches proposed above, a visual template has been created to report ideas in an organised way and enable discussions on deeper research needed. The template also enables to capture emerging value opportunities ideas from previous steps. The template is shown in Figure 10.

¹² Latest review of market prices for secondary materials is available here (4th August 2017): <https://goo.gl/sDC1o6>

1 Results from Market Analysis (Indicate resource scarcity / price)	2 Results from MAESTRI waste exchanges database (standard queries A and B)	3 Results from Organisation Network Analysis (4 What needs deeper research? (Indicate information to be searched)
++ market value	Exchanges involving the waste resources (write down the resource and its use):	Who in your supply chain / networks may have similar waste resources? (write down name/ type of company and the resource)	What do they do with the waste resources? Do you have any information regarding volume, frequency or quality of waste resources generated?	Separation or extraction methods? Available technologies?
	Sectors with similar waste (write down the sector and type of company when known):	Who in your supply chain / networks may need any waste resources? (write down name/ type of company and the resource)	What do they do with the waste resources? Do you have any information regarding volume, frequency or quality of waste resources required?	Volume, frequency or quality of waste resources needed?
	Sectors needing our waste as resources (write down the sector and type of company when known):			Structure of target industry / supply chain?
-- market value				Forecast of target market, next 2-3 years potential demand?
5 Value opportunities What are the emerging value opportunities from these analyses?				

Figure 10 Template to support the How to value waste step within T4IS

3.3.2 How to value waste - Other tools

How to value waste - Complementary tools

MAESTRI Library of case studies > this tool is described in D4.2 “Prototype library of case studies linked to a waste database” (BENEDETTI ET AL., 2017) and earlier in this document. The library of case studies in particular can be used to gain useful insights and information related to activities conducted by other companies to valorise the same type of waste (e.g. what analysis and treatments they have performed).

How to value waste - Secondary tools

Other repositories for potential uses identification

Other waste databases have been developed and are available online. Most of them are the result of previous or ongoing projects on IS conducted by different research groups or of governmental activities. In the following, a selection of these tools is briefly presented, mainly considering those that are freely and currently available. They could be used as a source of information as regards other companies having similar waste or companies requiring a particular type of waste.

1. RecycleBlu.com¹³: this website provides different tools and services for companies to effectively manage their waste. It has a “Marketplace” section where companies can advertise their available waste. Information on resources available and companies providing them are free accessible, a subscription is required to contact advertising companies.

¹³ <https://www.recycleblu.com/>

2. Smileexchange.it¹⁴: this is a website allowing companies to advertise their available/required resources. It allows to search resources by typology and basic information on the type of resource available/required are directly accessible. It is possible to sign in for free to access additional information and make enquiries on resources.
3. IS DATA¹⁵: is an open platform developed by TU Delft for collecting and supplying structured information on IS. It includes a repository of case studies and best practices that can be freely downloaded.
4. eSymbiosis (CECELJA ET AL., 2015)¹⁶: is the output of a project funded by the European Commission. It is a web-based platform which enables users to contribute to the website by submitting details on their resources and exchange experiences. It is necessary to register to the website in order to access all of the information.
5. Materialsinnovationexchange.com¹⁷: it is a marketplace where companies can advertise or buy waste materials. Information regarding the material are available, including quantity, type of packaging, location, price, etc. and the company providing/requiring them are available.

3.4 How to exploit waste

This step aims at supporting the Identification of the actions to exploit better the resources subject to IS, as defined in previous steps. This step is about configuring and developing the value creation and delivery systems (key activities, partners, channels, resources) that can make the best use out of the waste materials valued in the previous step. According to previous findings in Task T4.1 “Challenges and success factors for Industrial Symbiosis”, many characteristics for successful IS implementation are similar to those needed to make successful any other business endeavour. Taking this into consideration, this step builds on the last step proposed by Rana et al. (2017) in their sustainable business model process: *Step 5 – Configure and coordinate*. Similarly, it proposes as one of the primary tools the Business Model Canvas (Osterwalder and Pigneur, 2010). In order to adapt this to waste resources and their specific challenges, an additional tool is proposed at this step.

Complementary tools can be those that allow the estimation of benefits from a multi-value perspective, i.e. considering economic, environmental and social value. Therefore, LCA-based approaches in which a sensitivity analysis can be conducted are adequate to supplement the primary tools at this step.

IS can be more broadly understood as part of the “create value from waste” approach and it is suggested as one of the sustainable business model archetypes (Bocken et al., 2014). Therefore, the suggested secondary tools are mainly borrowed from the business model literature, specifically from the sustainable business models development literature.

¹⁴ <http://www.smileexchange.ie/>

¹⁵ <http://isdata.org/>

¹⁶ <http://esymbiosis.clmsuk.com/Home>

¹⁷ <http://www.materialsinnovationexchange.com/>

3.4.1 How to exploit waste - Primary tool

IS exchange configuration analysis

Description

This analysis consists of two steps. The first one target specific dimensions / issues related to IS exchanges while the second one uses the Business Model Canvas to configure how the company will deliver value through the IS exchange. The specific IS dimensions are based on findings obtained during the toolkit development process and previous research within WP4 “Industrial Symbiosis”. These dimensions are: resource type, volume generated, frequency of generation, remaining chemical / mechanical properties, resource state / condition, target sector / industry, and geographical distance.

A visual template (Figure 11) has been initially developed to be further tested as enabler of discussions for IS exchange building considering both the donor side (i.e. company producing the waste resource) and the receiver side (i.e. company potentially incorporating the waste resource into their operations).

How to use the tool

A value opportunity for a potential IS exchange needs to be selected based on the information gathered in the previous step. Criteria to be considered could be perceived value to be gained (according to the perception of the market), perceived easiness to find a potential reuse (according if more or less experiments are thought to be necessary, to previous guessed or heard application etc.) Then, the next steps will be followed:

1. IS exchange building analysis, based on the visual template shown in Figure 11. Sub-steps are numbered in the template and can be described as:
 - Recover key information from previous steps that can be relevant for further discussions on operational and business aspects related to the waste resource
 - Follow the set of questions to discuss on the IS exchange key parameters from the donor perspective and the receiver perspective
 - Identify any additional information gap that needs to be covered to fully configure how the IS exchange will work
 - Finally, identify the unique selling point for this exchange to happen. This will be relevant for the definition of the value proposition in next step.

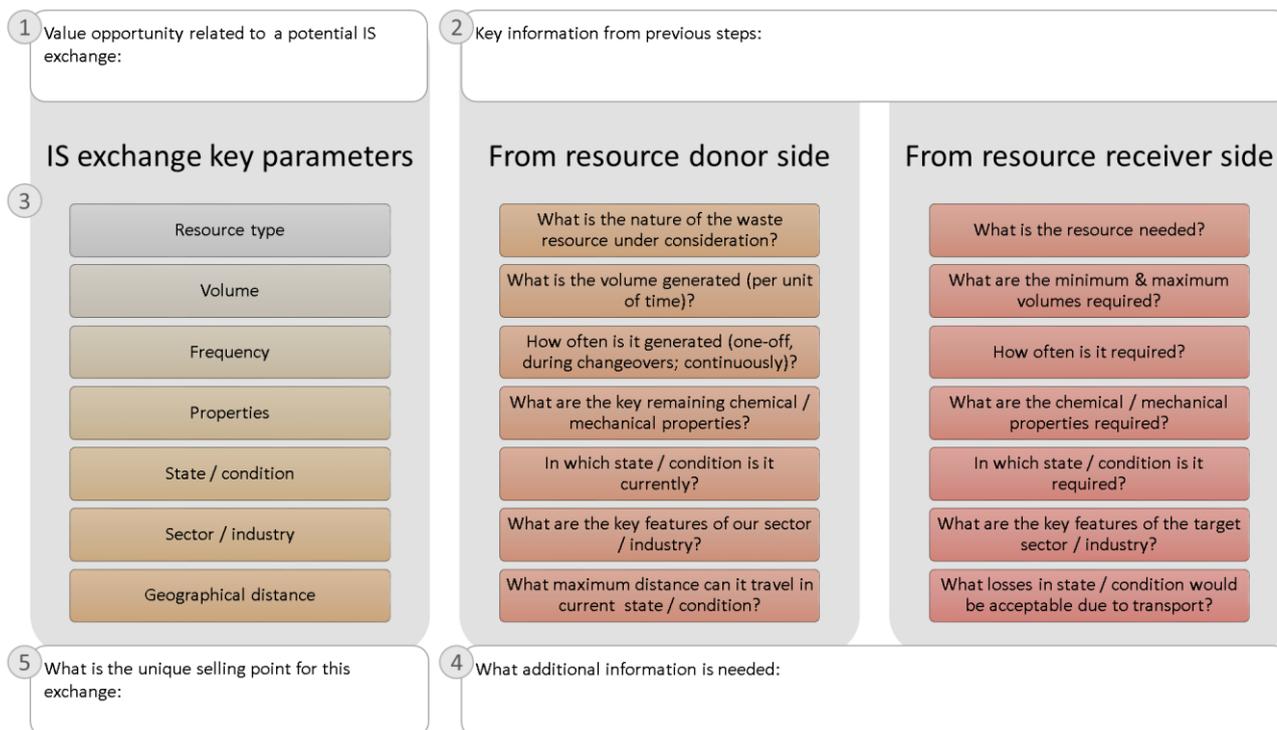


Figure 11 Visual template for IS exchange key parameters analysis

2. IS exchange configuration analysis, based on the Business Model Canvas template (Figure 12) developed by Osterwalder and Pigneur (2010)¹⁸. A suggested path to work with this template is the following.
 - o Define the value proposition
 - o Define the key customer segment/s (in this case related to the information of the receiver and target sector / industry already obtained in previous steps),
 - o Define the customer relations and the distribution channels to reach those customers (i.e. receivers of the waste resources)
 - o Define the key activities, resources and partnerships necessary to deliver the IS exchange
 - o Define the cost and revenue structure for the IS exchange

¹⁸ The Business Model Canvas can be downloaded from the Strategizer website: <https://strategyzer.com/canvas/business-model-canvas>

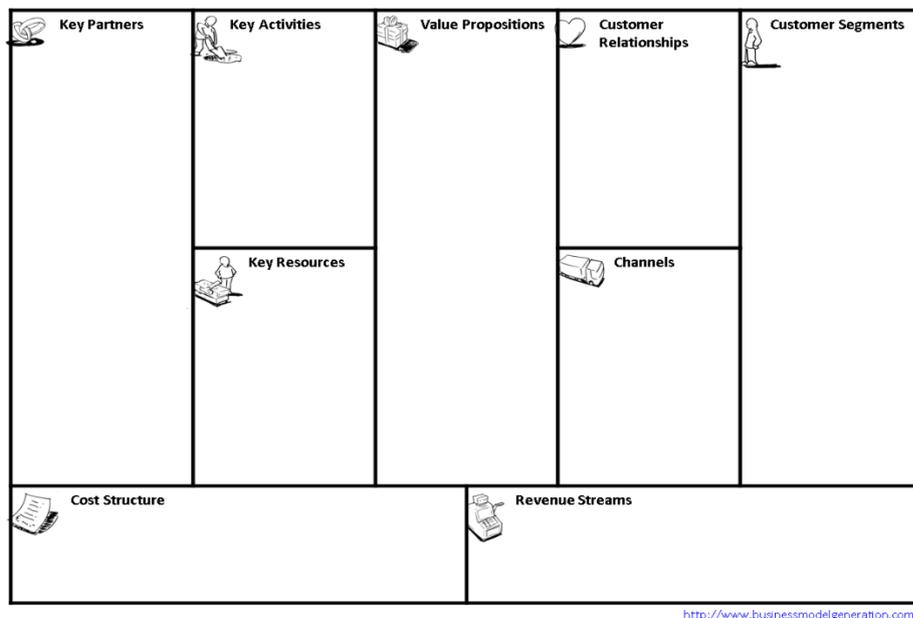


Figure 12 Business Model Canvas template (Osterwalder and Pigneur, 2010)

3.4.2 How to exploit waste - Other tools

How to exploit waste - Complementary tools

MAESTRI Library of case studies > this tool is described in D4.2 “Prototype library of case studies linked to a waste database” (BENEDETTI ET AL., 2017) and earlier in this document. The library of case studies in particular can be used to gain useful insights and information related to activities conducted by other companies to exploit the same type of waste (e.g. what key resources they have used or what key activities they have implemented, which customer segment they have targeted to exploit the same waste, etc.)

Eco-Efficiency Integrated Methodology for Production Systems (ecoPROSYS®) > is an approach to environmental performance evaluation based on the use of a systematized and organized set of indicators. Its main purpose is to help companies continuously improving their efficiency in resources and energy use. It is a valid support in the assessment of eco-efficiency performance and in related decision-making activities. Further description of this tool can be found in MAESTRI D2.3 “Simulation and decision support approach for sustainable manufacturing” (SILVA ET AL., 2016). It can be used in this phase to assess the impact that identified exchanges would have on the whole production system, by means of its simulation module.

How to exploit waste - Secondary tools

Once the waste resource has been valued, it is not anymore a “waste” and we suggest that it is treated as a product. At this stage, the company can apply its own product development process, if desired. We propose to follow a blue ocean strategy approach.

Blue Ocean Strategy (Kim and Mauborgne, 2005)

The Blue Ocean Strategy is not a specific tool but a philosophy, and it includes several tools (<http://www.blueoceanstrategy.com>). Within this philosophy, the metaphor of red and blue oceans describes the market universe. The blue ocean is an analogy to describe a potential area of market space that is not yet explored or known, where there is then no competition, capable of creating market demands and profitable growth for the company (Kim and Mauborgne, 2005). A Blue Ocean Strategy aims at systematically identifying blue oceans, i.e. market spaces where competition is irrelevant, by using tools supporting new and existing companies. The tools suggested are the *Four Actions Framework* (Figure 13), which can be represented in a four space grid, namely the *Eliminate-Reduce-Raise-Create Grid* (Figure 14) all proposed by Kim and Mauborgne (2005).

Raise	Create	Reduce	Eliminate
<ul style="list-style-type: none"> • What factors need to be raised above current standards? 	<ul style="list-style-type: none"> • What factors are not present but should be created? 	<ul style="list-style-type: none"> • What factors need to be reduced below current standards? 	<ul style="list-style-type: none"> • What factors are present but should be eliminated?

Figure 13 Four Actions descriptions (developed from Kim and Mauborgne, 2005)

<p>Eliminate (Describe actions)</p>	<p>Raise (Describe actions)</p>
<p>Reduce (Describe actions)</p>	<p>Create (Describe actions)</p>

Figure 14 Eliminate-Reduce-Raise-Create Grid (adapted from Kim and Mauborgne, 2005)

Quality Function Deployment (QFD) (Akao, 1990)

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The Quality Function Deployment (QFD) or “House of Quality” is a technique initially developed in Japan in 1965 to transfer quality principles from production process control to product design. It allows identifying matching and mismatching between product's characteristics and customer's requirements and, through the benchmarking with competitors or competing products, to define strengths, weaknesses, opportunities and threats for the business. It can be used for example to understand if and how much a new product created from waste satisfy customer's requirements and also how to increase the appeal of the new product compared to existing, non-waste-derived competing products.

4 Concluding remarks

IS can provide companies a means to improve their non-labour resource productivity. With potential improvement actions in the economic, environmental and social dimensions of business, the application of IS should be evaluated against other options for resource efficiency improvements. Concretely, a need for tools and methods that can support companies to identify and evaluate, at early stages of ideation, both the different possibilities for their waste streams and for enlarging their procurement activities by looking for symbiotic exchanges with other companies. Additionally, there is also a need to provide companies with tools and methods to support IS development process, especially as regards self-organised IS, and to help them defining actions to be undertaken. These needs were identified in D4.1 "Report on challenges and key success factors and gap analysis for industrial symbiosis" (HOLGADO AND EVANS, 2017) and led the development of the T4IS.

The results of previous tasks in WP4 "Industrial Symbiosis", the analysis of its interactions with WP2 "Efficiency Framework" and WP3 "Management system" and field sessions with MAESTRI industrial partners have informed the development of the T4IS. This set of tools and methods aims at provided a self-guided process to support companies to embark into the application of IS approach in their manufacturing operations. The design of the T4IS allows to have a standardised and structured approach to the identification and implementation of IS opportunities, but at the same time to have the flexibility and adaptability required due to the high influence of contextual factors on the process itself.

Table 6 summarises the key takeaways from each section of the T4IS, principles derived from previous activities and from the toolkit development process, and according to which the tools have been designed.

Table 6 Key takeaways from the steps of the T4IS

T4IS Steps	Key Takeaways
Whole T4IS	In order to implement IS, companies have to undertake a journey that would take them from having waste to get rid of to having waste resources to get value from.
How to see waste	Mapping the production process considering not only resources and waste flows, but also points where value creation and disruption happen is helpful to identify improvement opportunities.
How to characterise waste	Categorising and coding waste resources allow to keep track of potential improvement opportunities identified as well as to investigate, communicate and store information.
How to value waste	The identification of knowledge/information repositories as well as the creation/strengthen of networks to share information with other companies is vital to identify suitable value opportunities for waste resources.
How to exploit waste	It is important to analyse value opportunities for waste resources as new potential business model in order to highlight/consider the benefits they would bring to the business.

The T4IS will be under further testing with MAESTRI industrial partners and other companies outside MAESTRI consortium during next months. This will allow a final round of refinements to enhance its usability and flexibility as it will be tested in several different business contexts. Within MAESTRI testing phase, the integration of the T4IS with other MAESTRI tools and methods will also be further analysed as well as interaction activities defined.

In order to make the T4IS more accessible and facilitate its use by practitioners, a user guide for IS development is under development within the activities of WP4 "Industrial Symbiosis". This user guide will prescribe steps to engage in IS, supported by the use of the tools and methods from the T4IS.

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