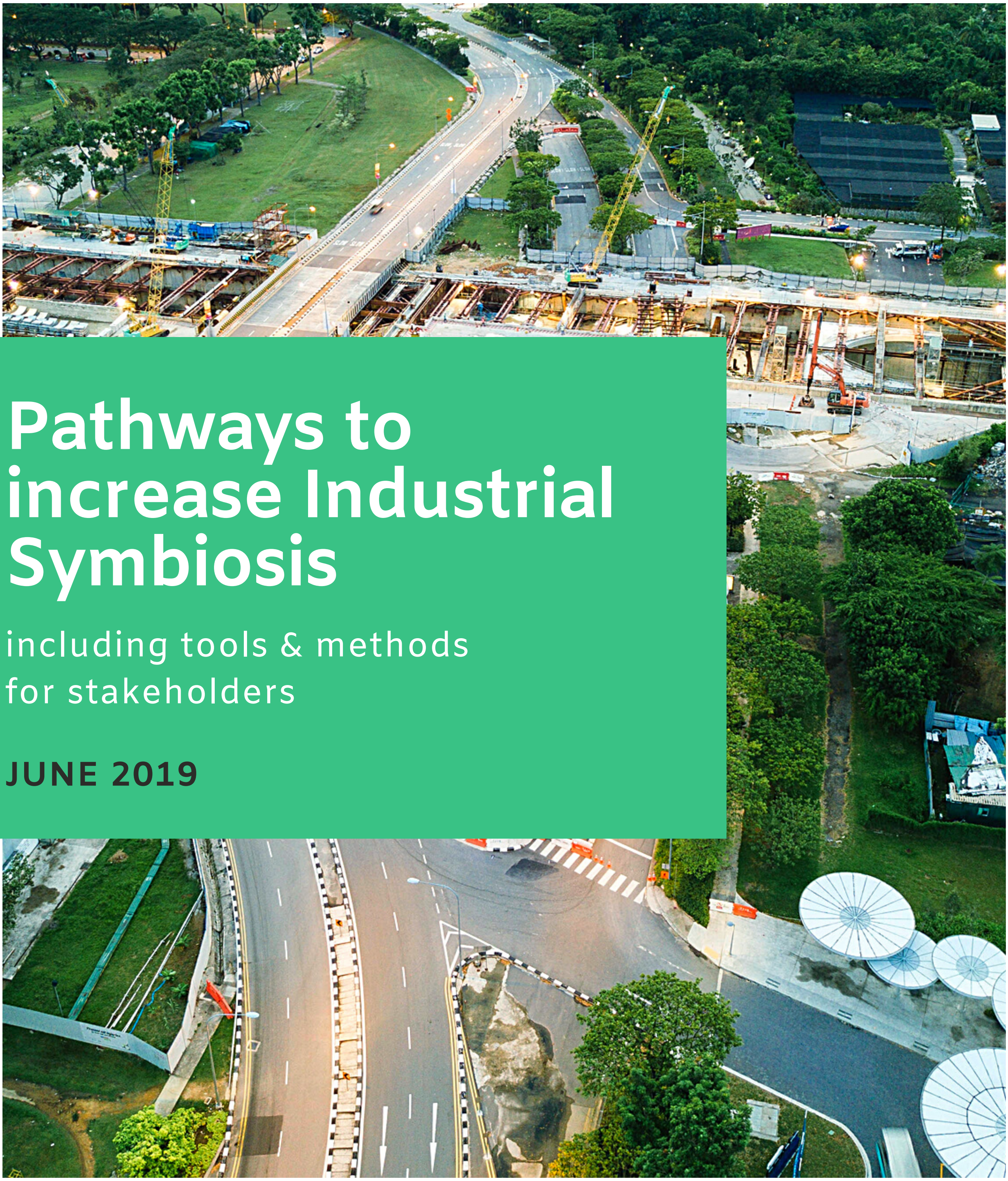

Pathways to increase Industrial Symbiosis

including tools & methods
for stakeholders

JUNE 2019

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Deliverable 2.4

Pathways to increase industrial symbiosis implementation, including tools & methods capable of being fully used by stakeholders

WP2 Pathways to foster resource synergies

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Authors

Name: Dr Doroteya Vladimirova

Organisation: University of Cambridge

Name: Dr Karen Miller

Organisation: University of Cambridge

Name: Prof Steve Evans

Organisation: University of Cambridge

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Figures and tables

Abstract

The objective of this report is to provide an insight into state-of-the-art tools and methods that could facilitate the implementation and enable stakeholder pathways towards self-organised industrial symbiosis.

We identify a set of tools and methods, which could be utilised by industry practitioners in their self-organised industrial symbiosis endeavours. A catalogue of selected state-of-the art tools and methods is presented. We look into the application and the benefits of these tools and methods.

Lastly, we develop recommendations for stakeholder pathways towards industrial symbiosis through the use of the selected tools and methods.

This report is extending the research findings in Deliverable 2.1 'Lessons learnt and best practices for enhancing industrial symbiosis in the process industry' and Deliverable 2.2 'The role of intermediaries and enabling technologies for industrial symbiosis initiation and implementation' in the SCALER project.

Introduction

The aim of this study is to identify state-of-the-art tools and methods that could facilitate the implementation and enable stakeholder pathways towards self-organised industrial symbiosis (IS). Our research suggests pathways to move from anecdotal one-off resource synergies to an organised application of resource synergies to address various forms of value uncaptured as a means to increasing resource productivity and competitiveness.

This deliverable has been directly informed by developments made by the Scaler project partners and the results from projects like MAESTRI and EPOS (SPIRE), SustainValue (FP7) and Business Models for Sustainable Industrial Systems (UK EPSRC), where the Scaler project partners have been at the forefront of the development of the tools under consideration for this deliverable. The report has been informed by the efforts invested in the development of these tools, which have all been created (some still in development) in collaboration with the network of stakeholders and partners of the projects, where the tools originated.

In addition, we further scrutinized the 25 case studies previously identified for Deliverable D2.1 and extracted a set of tools and methods, which have enabled the implementation of IS in the selected cases. In this report, we also considered tools and methods, which have been utilised by or recommended by industry experts, such as members of the SCALER Advisory Board and wider project collaborators. We also handpicked and placed the spotlight on certain tools, which were not found through the case studies applications, but were discussed in the literature as enabling examples. We provide a brief qualitative description of the tools and method and their main benefits.

In summary, in this report D2.4, we aim to identify and synthesise multiple inputs in a systematic catalogue of cutting-edge tools that can be accessed by industry users and used to facilitate their efforts in self-organising and implementing IS. We develop recommendations for the use and configuration of the tools to enable various stakeholder pathways based on the maturity of the tools and their suitability for various stages of adoption of IS.

This report, Deliverable 2.4, is based on the SCALER Work Package 2, Task 2.5. This report is part of a wider study which seeks to boost the application of IS in the process industry by considering non-technical and technical best practices, enabling technologies, key intermediaries and facilitating tools and methods.

1. Tools and methods enabling the adoption of industrial symbiosis

We compiled a library of tools and methods to further build up our body of knowledge concerning the implementation of industrial symbiosis. More importantly, we handpicked a set of tools developed (or currently in development) by the Scaler project partners. These tools have been tried and tested with the industry stakeholders of the respective projects where the tools originated from. The 6 tools in spotlight include the Cambridge Value Mapping Tool, the Sustainable Value Analysis Tool, the Sustainable Value Proposition Builder, the MAESTRI Toolkit, the EPOS Toolbox and the BE CIRCLE tool.

In addition, we created a select catalogue of 41 tools, methods, platforms and models (Table 2), which we identified through the 25 case studies in D2.1 and the literature, as well as through direct recommendations by industry and academic experts supporting the Scaler project.

1.1 Value Uncaptured Perspective

The Value Uncaptured Perspective (Figure 1) was developed by researchers at the University of Cambridge over the course of 5 years. This framework proposes 'value uncaptured' as a new perspective for sustainable business model innovation, and develops four forms of value uncaptured: value surplus, value absence, value missed and value destroyed (Yang, M., Evans, S., Vladimirova, D. & Rana, P., 2017).

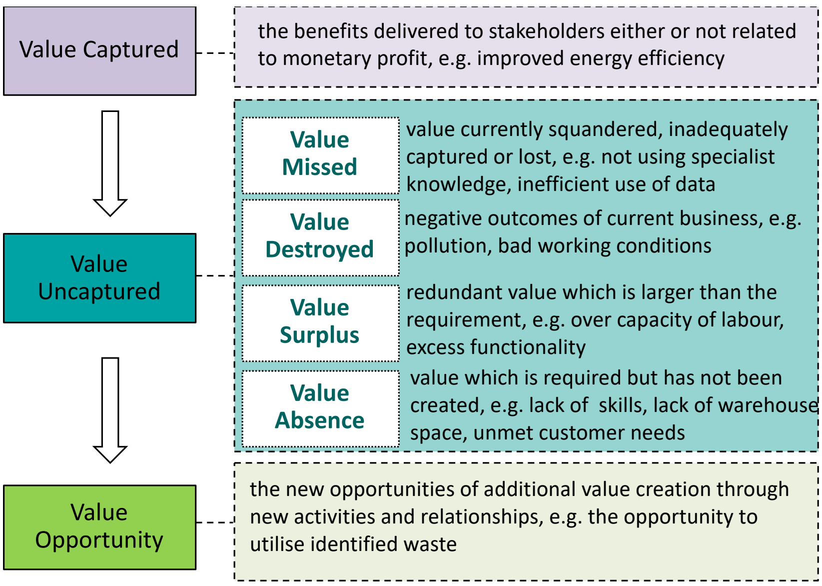

Figure 1 - Value Uncaptured Perspective for Sustainable Business Model Innovation (Source: Yang, M., Evans, S., Vladimirova, D. & Rana, P. 2017)

We are introducing the 'value uncaptured perspective' framework in this deliverable since it has informed multiple tools developed by the University of Cambridge in further national and EU-funded research. Such tools include the Cambridge Value Mapping Tool, the Sustainable Value Analysis Tool and the MAESTRI Toolkit, which we discuss in the next sections.

1.2 Cambridge Value Mapping Tool

The Cambridge Value Mapping Tool (Bocken et al., 2013; Vladimirova, D., 2016) has been developed and refined over the past 7 years. An early version of the tool can be traced back to the research carried out by the University of Cambridge for the EU FP7 project SustainValue (http://www.sustainvalue.eu/). The tool was later extended and refined by Cambridge researchers through the UK EPSRC project Business Models for Sustainable Industrial Systems (EP/L019914/1).

The tool uses a structured and visual approach to identify 'value uncaptured' in the form of failed value exchanges: value missed, destroyed, surplus, and absence. The exchange of value is analysed through the lens of each stakeholder in the business network, with the natural environment and society each being given its own voice and stake in the business.

In the context of self-organised industrial symbiosis, the Cambridge Value Mapping Tool can be applied in the early stages of ideation and the search for new opportunities for resource synergies, as well as a mechanism for network formation and alignment for IS.

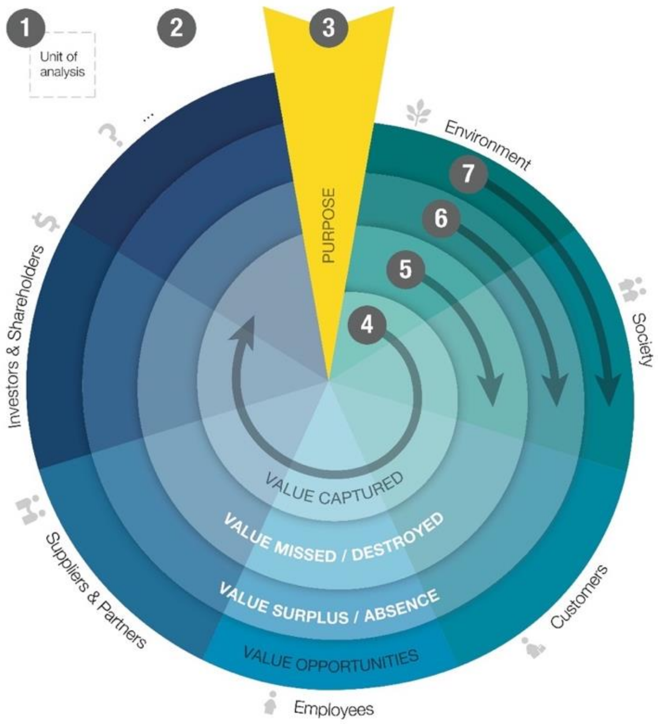

Figure 2 - Cambridge Value Mapping Tool
(Source: Vladimirova, D., 2016)

1.3 Sustainable Value Analysis Tool

Similarly to the Cambridge Value Mapping Tool, the Sustainable Value Analysis Tool (SVAT) adopts the ‘value uncaptured perspective’ but combines it with sustainable value and life cycle thinking to create a process for discovering new opportunities in the Beginning of Life (BoL), Middle of Life (MoL) and End of Life (EoL) of products and materials (Yang, M., Vladimirova, D., Rana, P. & Evans, S., 2014; Yang, M., Vladimirova, D. & Evans, S. 2017).

In the context of self-organised industrial symbiosis, the Sustainable Value Analysis Tool can be used as a qualitative analytical tool in the stages of ideation and in the search for new opportunities for resource synergies across a full value chain. The sustainable value analysis is best performed with the participation of stakeholders from the various parts of the value chain.

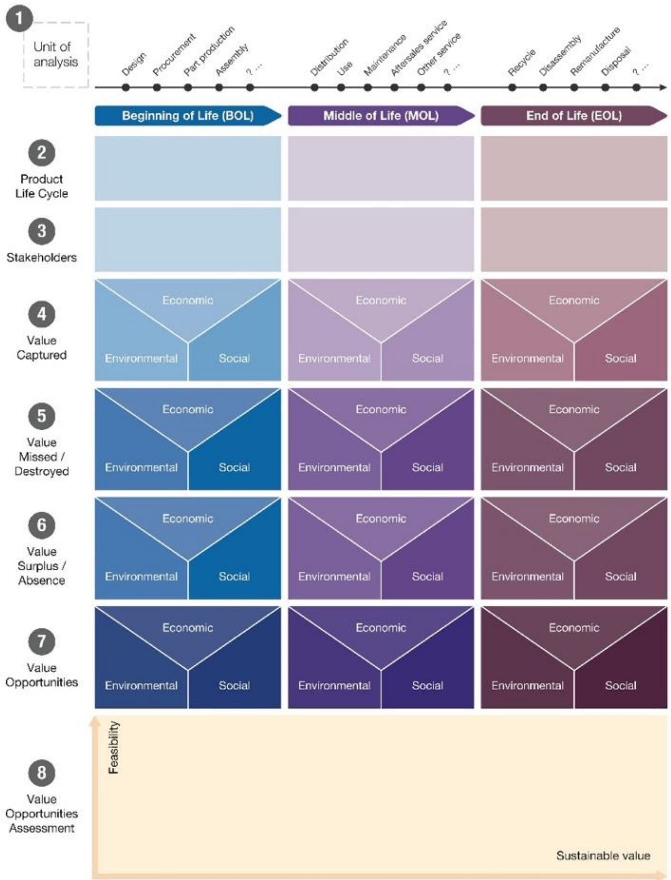

Figure 3 - Sustainable Value Analysis Tool
(Source: Yang, M., Vladimirova, D. & Evans, S. 2017)

1.4 Sustainable Value Proposition Builder

The Sustainable Value Proposition Builder is “a practical approach for helping innovation leaders to build value propositions that result in more sustainable businesses” (Vladimirova, 2019, p.1). This new tool was created to help companies build multiple value propositions and to facilitate stakeholder engagement (Vladimirova, 2019).

In the context of self-organised industrial symbiosis, the Sustainable Value Proposition Builder can be used to support the development and communication of value propositions to multiple stakeholders who play critical roles in the IS network.

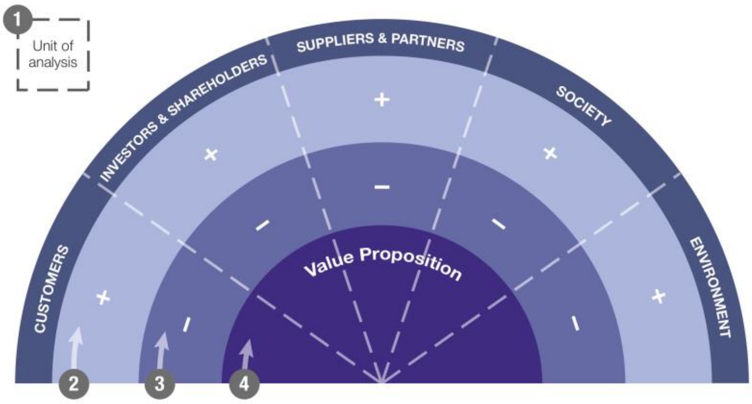

Figure 4 - Sustainable Value Proposition Builder
(Source: Vladimirova, D., 2019)

1.5 MAESTRI Toolkit

MAESTRI is a EU Horizon 2020 project undertaken within the SPIRE-PPP initiative. It has run for almost four years with multiple partners and the project finishes in August 2019. Full details of MAESTRI can be found at: https://maestri-spire.eu.

The aim of MAESTRI is to accelerate sustainability within the European manufacturing and process industries. MAESTRI is formulated as an online platform designed for users to self-guide themselves through an IS set up and acceleration process. At the heart of the system is the MAESTRI Total Efficiency Framework that is illustrated in Figure 5, which is composed of four elements or what are termed “pillars” (MAESTRI, n.d.) The pillars are:

1. A management system directed at both process and continuous improvement.

2. A set of efficiency assessment tools to help identify strategies for improvement and optimisation.
3. An IS toolkit that targets material/ energy exchanges.
4. A platform centred on the Internet of Things (IoT) to help users streamline IS implementation.

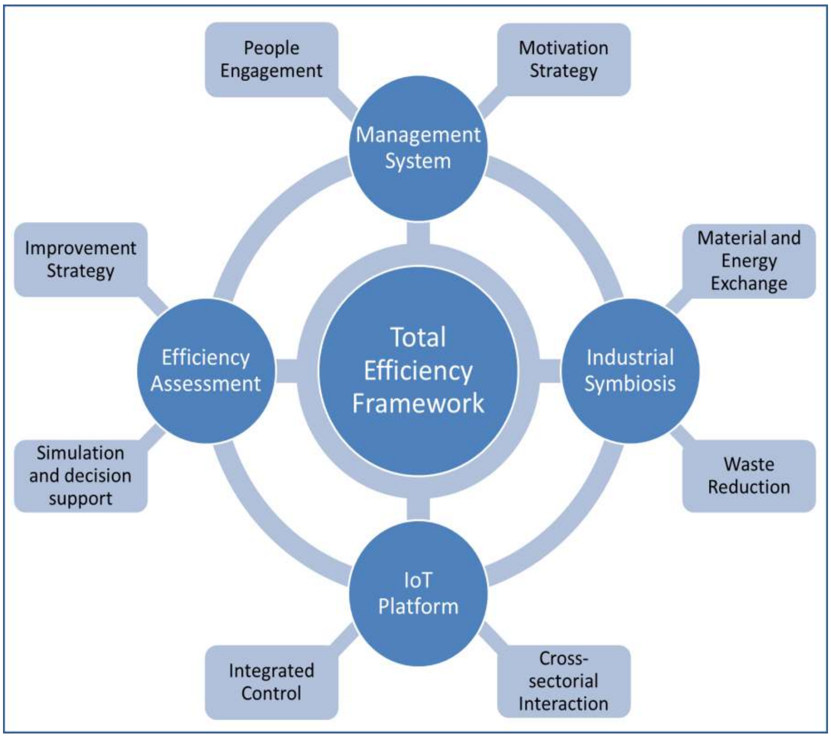

Figure 5 - Total Efficiency Framework (Source: MAESTRI)

Within the overall Total Efficiency Framework are multiple different methods and tools. Some are bespoke and have been developed in association with the project partners. Other tools and methods have been adopted or modified from existing sources to suit the needs of the target audience embarking on an IS journey.

Three workshops were convened to develop or pilot certain of the tools and methods with practitioners beyond the industrial partners that were directly involved in the project. Academics and representatives from other interested parties also attended - for full details visit: https://maestri-spire.eu/project/

In relation to the tools and methods within the MAESTRI 'compendium', the T4IS toolkit has been built to enable users to self-guide themselves through a process to identify potentially exploitable waste products, and develop appropriate value creation strategies. Further detail on the T4IS toolkit is available at: https://maestri-spire.eu/wp-content/uploads/2018/01/MAESTRI-D4_3_v1_rev.pdf

Four 'How to' questions are used to structure the T4IS toolkit in a stepwise fashion and these are as follows:

1. See Waste - how to identify resources within manufacturing processes and facilities?

2. Characterise waste - how to describe the properties of the resources that have been identified in question 1?

3. Value Waste - how to estimate what the resources could be worth?

4. Exploit Waste - how to most effectively utilise and valourise the resources?

Table 1 - Overview of T4IS tools and methods structured within four steps (Source MAESTRI)

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)

As seen in Table 1, the MAESTRI team recommends starting the process with Value Uncaptured Analysis, which has been described in section 1.1. Thus, well established methods developed by Yang et al., (2017) described in the paper: *"Value uncaptured perspective for sustainable business model innovation",* have been used as the foundation for the MAESTRI toolkit.

From the multiple tools and methods in the T4IS, users, depending upon the specific context of their organization and the industry within which it is situated, select what they consider will work best. Thereafter the process embedded in the T4IS is designed for users to work methodically through each question. According to the MAESTRI team by following the methodology users build knowledge, which is augmented by other more specific tools and methods, which are featured on the platform structured under the other three pillars. They are also encouraged for example, to refer to the MAESTRI Library of Case Studies for details on best practice. More detail is provided, both of the approaches to use the methods briefly sketched out in this section, and on other tools/methods held within the MAESTRI compendium at: https://maestri-spire.eu/downloads/

Given that the MAESTRI project is still running at the time of writing this report, and many of the tools and methods are in the early phase of testing, we would characterise the MAESTRI toolkit as immature. This is based upon comparisons to highly established tools that have been extensively tested, such as the Cambridge Value Mapping Tool (Vladimirova, D., 2016).

1.6 EPOS Toolbox

The EPOS toolbox is being developed within the context of the European H2020 project EPOS "Enhanced energy and resource Efficiency and Performance in process industry Operations via onsite and cross-sectorial Symbiosis" (https://www.spire2030.eu/epos).

The toolbox has been built on the calculation engine "Osmose", developed by EPFL, which uses mixed-integer linear programming optimisation methods to identify optimal solution sets from a superstructure of defined technologies. Included in the superstructure is a modelbase of cross-sectoral and generic technologies which represent a typical operation in each EPOS sector (cement, minerals, steel and chemicals). The toolbox includes a wide range of key performance indicators (KPIs) which include, for example, operating costs, investments costs, climate change, human health impacts. The toolbox is presented with a user-friendly interface.

The toolbox has undergone and will continue to undergo testing from all EPOS partners, mainly the industrial partners, since the blueprints that are used in the tool were provided by the latter. The toolbox is still undergoing development, until the end of the EPOS project in September 2019. Once complete, the toolbox will be available via an online platform.

The main steps when using the tool are:

1. Describe your industrial site (i.e. location, industry sector.
2. Describe your potential synergy partner(s) or search automatically for a potential partner(s) based on sector and location.
3. Customise the parameters of the default blueprint values.
4. Validate the synergies that are automatically detected, based on the sectors being modelled.
5. Define optimisation objectives for the calculation, as well as any other KPIs.
6. Results are calculated and displayed in a user-friendly manner.

Figure 5 displays the page where the user selects the optimisation objectives and KPIs.

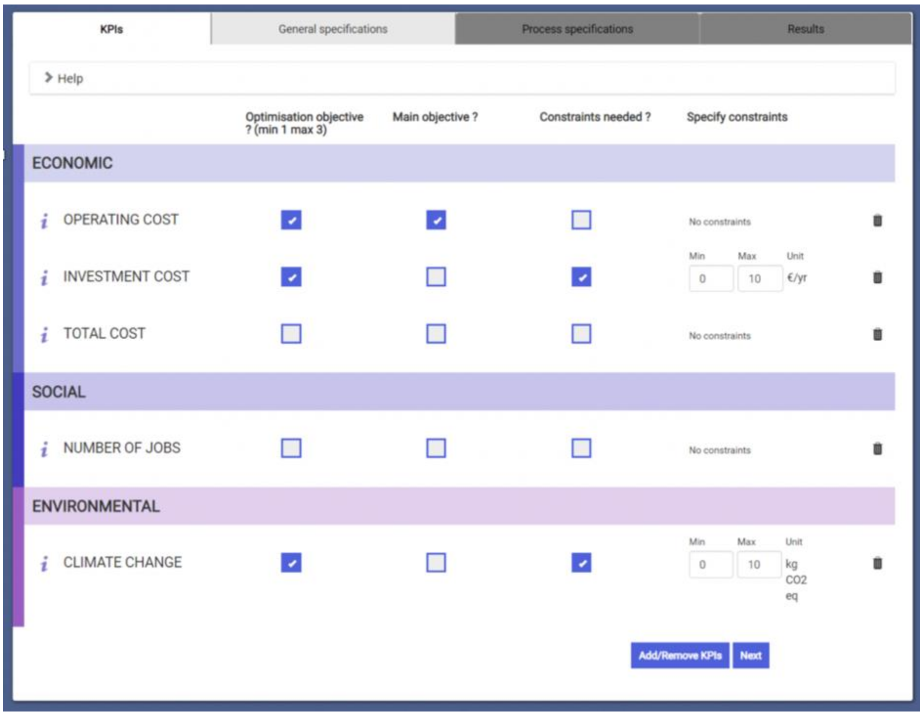

Figure 5 - Objectives, constraints and physical units of selected KPIs (EPOS toolbox)

Figure 6 is a preliminary visualisation of how optimisation results may be displayed. The results can be visualised in a column chart format (each column represents a solution), or a table format (each line represents a solution). The user can select / de-select the solutions to be shown in the column chart.

Figure 6 - Results shown in column chart and table format (EPOS toolbox)

1.7 BE CIRCLE Tool

The BE CIRCLE tool and service, which is web based was developed over a period of two years as an EU project. EIT Climate-KIC were the lead with partners that included: ENGIE, ARX IT, Ecole Polytechnique, Provadis Hoechschule, CNR and INSPIRA. The website is accessed at: www.be-circle.com.

The aim of the platform is to use generic non-confidential geodata to enable the design of both cities and industrial clusters with closed resource loops, i.e. of energy, water and materials. The platform works at a local scale and helps to raise the competitive nature and environmental profile of the region (and the firms located within) that are under scrutiny. In 2018, three pilots were conducted at the following sites: INSPIRA, Hoechst IndustriePark and the Port of Dunkirk. Figure 7 provides some detail on each of these pilots.

After the development process BE CIRCLE has been used for five months. The main adopter of the tool to date is ENGIE Lab Laborelec, which is a large company that uses the platform to provide substantive benefits to their clients. These include local authorities, various ports and other industrial firms. Further developments are underway to increase the usability of the tool.

Figure 7 - Image of BE CIRCLE pilot sites (BE CIRCLE, 2019, p.5)

The BE CIRCLE tool follows a “map, analyse, simulate” approach (BE CIRCLE, 2019, p.3) that breaks down as follows:

1. Map

- Open access data is used to generate a local industrial map – this map provides details of current infrastructure and facilities. It also reveals the predicted resources that are needed as inputs as well as the outputs.
- The platform helps identify the optimal site for any new plant using geodata - this encompasses for example any risk areas, existing networks and protection zones.

- Identification of the “stock of resources and level of autonomy, i.e. consumption vs production” (BE CIRCLE, 2019, p.3).

2. Analyse

- Determination of both the output providers and input receivers in the locality, i.e. of water, energy and materials.
- Identification of potential exchanges using most compatible sectors.
- Optimal matching of industry sectors and technologies to locality ecosystem in relation to resource flows.

3. Simulate

- Exchanges between providers and receivers using appropriate technologies.
- Scenarios in relation to cost KPIs, i.e. CAPEX and OPEX and environmental factors, i.e. greenhouse gases, water and energy circularity.

Figures 8 and 9 below capture the approach used to model the pilot for the Port of Dunkirk.

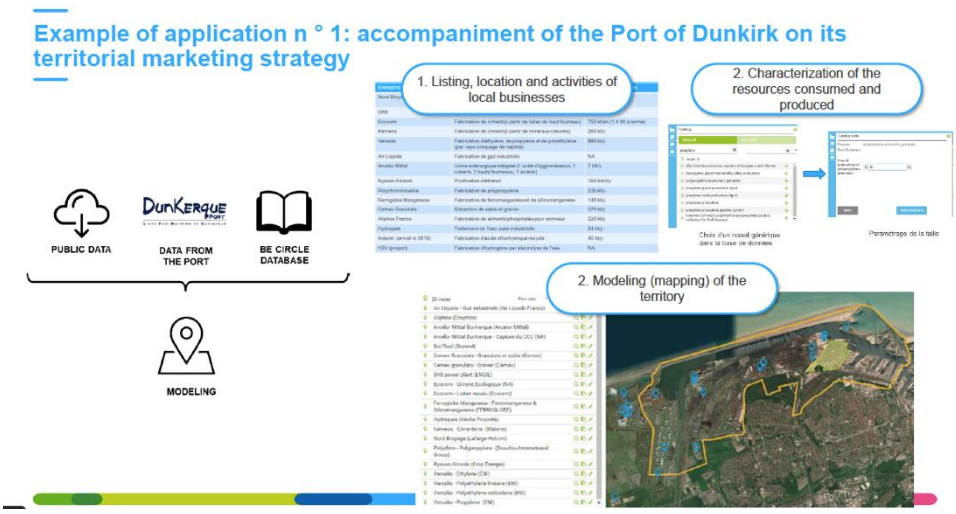

Figure 8 - Image of geodata mapping for to model Port of Dunkirk using BE CIRCLE tool (BE CIRCLE, 2019, p.7)

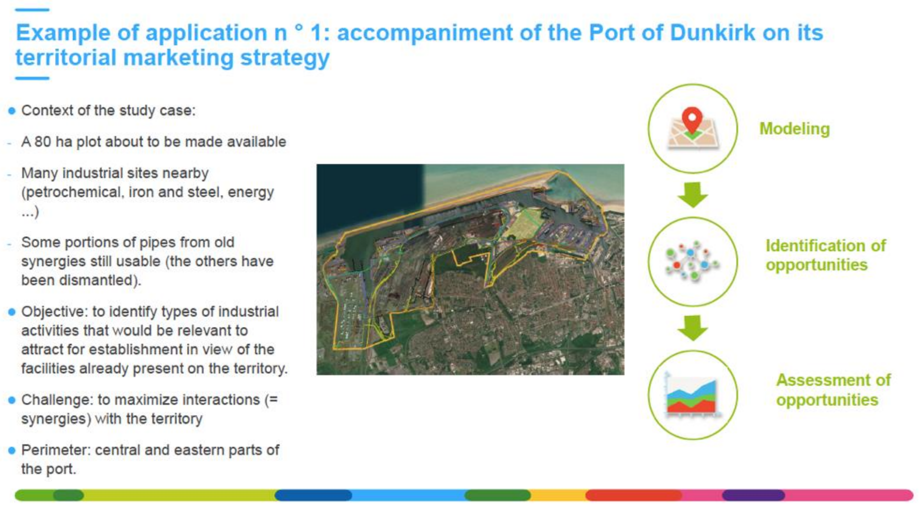

Figure 9 - Image of three stages taken to model the Port of Dunkirk using BE CIRCLE tool (BE CIRCLE, 2019, p.8)

2. Expert enquiry on industrial symbiosis

The SCALER project carried out an expert enquiry on adopting IS in Europe in May-July 2018. The enquiry was aimed at businesses and practitioners involved in various stages of IS implementation - from emergent to fully implemented - in all sectors. We invited international IS experts to share their experience.

The survey questionnaire was designed to inform multiple tasks in WP2 and WP3 and contribute to deliverables D2.1, D2.2, D2.3 and D2.4 respectively. In this report, only responses to questions that inform the present deliverable (D2.4) are presented. Seventeen respondents representing twelve sectors and eight countries participated in the expert enquiry. The results of the survey data analysis concerning the use of tools enabling IS are presented next.

Throughout Scaler, the results from the survey have been used as a means of triangulating our findings from the various other data sets generated in the project rather than a standalone output.

2.1 Do you use specific tools to help with the identification and implementation of resource synergies? If yes, please specify.

Out of the twelve responses to this question, two companies replied that they do not use any tools. One company replied that they are in the process of building their own tool and one company is investigating what tools are available.

Tools and methods identified and used by the remaining eight respondents to this question include the following:

- Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) tools.
- Site and regional mass balances for raw materials, energy (heat) and water.
- A "smart" solution for synergy identification based on a combination of structured queries, pre-conditioned "best practices" and algorithms for machine learning.
- Tianjin TEDA Eco Centre plays the coordinating role of Sharing Platform in promoting industrial symbiosis, energy conservation and environmental protection of industrial parks.
- Information. The most important tool is to be aware about the needs of different sectors.
- Own IT tool for all sub-products in our plants.
- Procurement of new raw material is mainly made in the internet.
- Finding new partners is improved with the utilization of ORBIS (database) or LinkedIn Professional.

2.2 What other tools, existing or not, would help you identify and implement resource synergies?

New IS tools required and suggested by the respondents include:

- Database on patents enabling resource synergies.
- Database on already existing and running synergies.
- Database on good practices collaboration with experts from research and university.
- Standards on quality of secondary raw materials.
- Database (available for free, at least affordable) on raw materials costs and on waste management land-filling costs.
- A flow map.
- Information platform for findings professional third-parties when seeking additional partners for the pre-conditioning and additional manufacturers with multiple waste streams.
- Database of industrial locations.
- A tool that takes inventory of all sub-products coming out from the sector; then puts together sub-products from one sector and connects to other sectors; giving visibility of what other sectors need. Having the information and providing information to other sectors regarding sub-products would be highly valuable.
- Databases/platform where you can find the materials, the available quantities, the prices and the location.

3. Pathways to self-organised IS

Finally, we outline high level stakeholder pathways (Figure 10) that could be pursued through the use of the tools, which we put in spotlight in this report, as well as through the use of the outputs concerning synergies and technologies selection emerging from Scaler WP3.

We suggest that a good starting point would be to better understand the value uncaptured in the system and to turn value uncaptured into new opportunities for resource synergies. This process can be supported by tools like Cambridge Value Mapping Tool and the Sustainable Value Analysis Tool presented earlier in this report.

Given the importance of the intermediaries, change and knowledge agencies/agents presented in D2.2, we argue that governments and authorities at all levels need to consistently focus on, and provide enduring support for these vital agencies/agents who can initiate and facilitate co-ordinated and self-organised IS networks.

Intermediaries could facilitate the selection of tools to be used, such as the ones presented in this report, followed by the identification of resource synergies and selection of technologies to help realise the most viable synergies. Continuous assessment of the various IS options needs to be performed before a new business model for IS can be confidently designed by the key stakeholders in the IS network.

Support through adequate funding is of the foremost importance, with appropriate policy making and dynamic communications as underpinning elements.

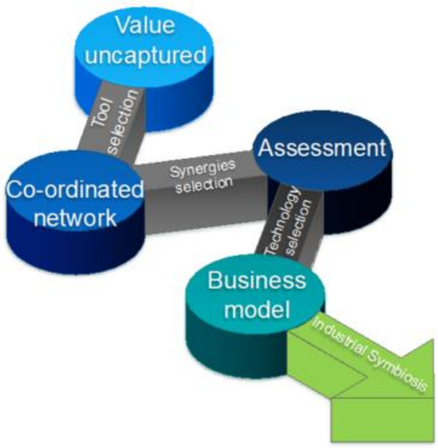

Figure 10 - Pathways to IS

4. Concluding remarks

As a result of the analysis undertaken in relation to the tools, methods and pathways to self-organised IS, we are now able to provide some concluding remarks.

Firstly, we conclude in line with our previous findings in D2.1 and D2.2 that there is a panoply of tools and methods available currently. Potentially we have also under represented what is available given the focus (in alignment with our methodology), on tools and methods identified in the case studies and literature (2016-2018), from other IS research projects and direct stakeholder inputs. Some of these tools and methods have been extensively tested and are well established, e.g. the Cambridge Value Mapping Tool and the SYNERGie®4.0 platform developed by the NISP. Others are relatively immature and need further exposure to provide evidence that they are easily accessible and applicable for managers, for example the MAESTRI T4IS. We have, however, found numerous examples where tools and methods are unsupported, i.e. in some cases links to platforms no longer function. On the basis of what was found to date, we suggest that providing more tools is unlikely to accelerate the scaling up of IS through self-organised approaches by managers.

Secondly, within the gamut of tools and methods that we have analysed is a wide spectrum that ranges from highly specific mathematical modelling to ‘soft’ methods such as the Sustainable Value AnalysisTool. Often it is unclear to users what tools and methods are appropriate at particular points within the IS development process, and some are highly context specific. For managers who are seeking to self-organise an organisation along the IS journey this presents a significant challenge. This is a similar scenario to the difficulties presented by the diverse range of technologies identified previously in D2.2.

With this backdrop, and in conjunction with our findings from D2.1 and D2.2, there are however some strongly positive pointers. Successful IS scale up is an intensely human activity and here intermediaries, change and knowledge agencies/agents come to the fore. Their knowledge and skills, in relation to selecting the most appropriate tools, methods and technologies, enables organisations and mangers to short-circuit what is intrinsically a highly complex process.

Table 2 - Tools / Methods for Industrial Symbiosis from the case studies, literature & expert recommendations

Tool	Description	Potential Benefits	Source
SYNERGie®4.0 Platform and Database	A well tested ICT resource management database and platform, enabling organisations to reduce cost, risk and environmental footprint through efficiently identifying resource reuse opportunities. Tool available in nine countries to record resources/make matches.	Shortens time and reduces effort of companies. Provides integrated mapping of resources to prioritise local sourcing and reuse opportunities. Advisor guides characterisation of resources for reuse and recommends opportunities based on machine learning (AI). Internal and supply chain KPI reporting aligned with stakeholder requirements. External data set upload for system pre-population.	International Synergies (former NISP): http://www.endustriyelsimbiyoz.org/wp-content/uploads/2013/02/industrial-symbiosis_uk-nisp-and-global-experience_31.01.2013.pdf https://www.international-synergies.com/what-we-do/synergie40/
MAESTRI Platform and Database	MAESTRI (still in development) in addition to tools and methods described previously in section 1.5 has: Management System composed of: A) Eco Orbit View - method that helps identify areas in production processes where managers should focus improvement activities; B) Focused Gemba Walk, direct observations of problems/ processes to understand the cause of problem and identify improvements to permanently eliminate it; C) Retrospective Analysis to rapidly find cause of problem; D) Eco Lean Management Board - visual method that provides control of Lean Management system; E) Efficiency Framework with integration of i) ecoPROSYS (Environmental Performance Evaluation (EPE), Life Cycle Assessment (LCA), and Cost and Value Assessment/Process Based Cost Model (PBCM); and ii) MSM (Multi-Layer Stream Mapping (lean based overall efficiency assessment method).	Compendium of tools and methods to assist users in self-organisation of IS.	https://maestri-spire.eu See also: Baptista et al., (2018); Holgado et al., (2018)

	The Efficiency Framework is designed to maximise process digitalisation, sensor integration and align for Industry 4.0. F) IoT - data streaming via an IoT Platform providing “dynamic assessment” plus “monitoring capabilities to feed efficiency and eco-efficiency tools” (MAESTRI).		
Sharebox or SYNERGie 2.0 Platform	Platform (under development) to share industrial process resources. Functions include modeling of waste/ energy exchanges, identification of matches between company supply and demand, analysis of process efficiency and monitoring of resource exchanges. Platform will ultimately manage process resources, including site, energy, waste and recycling resources.	Functions for users include: Input-output modelling of waste and energy resources; supply and demand matching; process efficiency analyses and modeling of optimal conditions for IS (economic, environmental, social).	http://sharebox-project.eu/partners/
eSymbiosis Platform	Platform that targets synergies between registered users of the site. Users provide profile and information on resources for sale/ sharing; eSymbiosis generates visual map by matching different actors who can negotiate / exchange resources. Case studies provide information of benefits/ encourage wider synergies implementation.	Intended for use by industrialists/ engineers/ technicians with good level of knowledge about on-site resources. After registering and inputting resource data, matches for potential synergies are identified. Resource types are displayed with quantity, validity period and relevance ratio. Ratio calculated using ontology based on factors including resource type, name, validity period and quantity.	http://esymbiosis.clmsuk.com/Home
SymbiOPOrto Platform	Platform for the promotion of synergies in the metropolitan Area of Porto.	Information available to companies registered on portal: types of waste streams in MPA taking into account registered companies; location and amount of waste; examples of efficient waste management in industry; information on potential for waste.	The SymbiOPOrto portal, operated under the AMP URBINOV project is the responsibility of LIPOR and the Metropolitan Area of Porto: https://symbioporto.org/

Italian Platform for Industrial Symbiosis (operated by ENEA) Platform	Platform has a Central Manager (ENEA) and integrated system of ICT and DB tools for management of single users (companies), their data (resources), and makes connections using information (including synergies that can be found between users). Platform has GIS system which localises registered companies on a map.	Uses geo-referenced data to identify opportunities between companies and helps establish networks between companies and stakeholders. Tool then helps companies in sharing resources (materials, energy products, water, services and expertise) and platform has other operational tools (regulation and BAT databases, quick LCA and Ecodesign tools, etc.).	https://www.resourceefficient.eu/en/intermediary/enea See also: Cutaia et al. (2015)
ISDATA (Industrial Symbiosis Data Repository) Platform	Open source platform for collecting and supplying structured IS information and providing source of best practice activities. Provides case studies, classification codes support through visualisation and searchable interface for European Waste Classification codes, and automatic suggestions for NACE and EWC codes.	Platform enables various user segments to utilise IS data in conjunction with other open/ proprietary data sets. Various tools to support utilisation of various data sources assists platform users.	http://isdata.org See also: Maqbool, Alva and Van Eetvelde (2018)
Symbiosis 3.0 Platform	Database of 300 organisations from Flemish industry; database mapped 2000 potential opportunities for flows of raw materials and technologies between companies.	Web based platform designed to help companies identify routes for waste as outputs and sources of by-product as input materials.	https://ovam.be/symbiose-verzilvert-reststromen See also: Maqbool, Alva and Van Eetvelde, (2018)
iNex Platform	Provides synergy identification and knowledge support about methodologies to users; platform helps solve recycling problem and address gaps in knowledge for waste producers and waste recyclers/users.	Platform developed by IS facilitators with big data techniques and in-depth knowledge which provides strong focus on matchmaking through synergy identification.	https://www.inex-circular.com/en/inex-plateform See also: Maqbool, Alva & van Eetvelde, (2018)
CIRCULATOR Platform and Tool	Self-service tool and open platform for knowledge sharing on strategies for circularity.	Provides information to user in form of existing cases of business strategies for circular businesses.	http://circulator.eu//mix-your-strategies See also: Maqbool, Alva & van Eetvelde, (2018)

Collaboration Platform with Database Engine for Waste-to-Resource Matching	Online platform with database engine to provide information on what resources can be recovered from wastes or by-products, and what wastes or by-products can be used as substitute raw materials/ what technology or processes are required to make waste-to-resource conversion occur.	Designed for users to easily store/ read/ manage data for waste-to-resource matching; uses visualisation capability to allow users to intuitively determine what resources can be recovered from wastes (or by-products), or what wastes can be used substitutes for their raw materials.	Low et al. (2018)
SMILE Resource Exchange Platform	Part of Irish National Program open access online platform for businesses to connect/ identify opportunities for resource exchange. Platform is coupled with service provided by local consultants. Database holds information on companies, and resources that can be transacted.	Designed to breakdown information and communication barriers between stakeholders to provide opportunities for synergies; facilitates contacts between supply and demand sides on platform.	http://www.smileexchange.ie/about-us See also: Maqbool, Alva & van Eetvelde (2018)
Looplocal Tool	Visualization tool assists in: 1) Simplifying identification of regions with potential for new industrial symbiosis facilitation activities; 2) Enabling proactive and targeted marketing of potential exchanges to companies in specific regions and 3) Assisting facilitators to assess various strategies for engagement.	Heuristic visualization tool to support strategic facilitation of industrial symbiosis in target regions.	Aid et al., (2015) Also see: van Capelleveen, Amrit & Yazan (2018)
Multi-criteria Spatial Decision Support System Tool	A multi-criteria spatial decision support system for IS planning.	Assists managers and planners with complex /partially structured spatial problems to assess viability of IS in relation to location.	Ruiz et al., (2012)

Optimization-based Negotiation Framework Tool	Combines “principles of rational allocation of benefits with consideration of stability/ robustness of coalition to changes in cost assumptions by analysing its stability threshold” p. 496.	Allows users to make robust decisions concerning current/ future interactions in EIPs.	Andiappan, Tan & Ng (2016)
Recovery Potential Indicator Tool	Tool allows analysis to compare current material use in global (paper) life cycle with ideal scenario in which recovery potential of all major waste flows is utilised.	Indicator provides estimates of potential improvements in complex material systems – useful for policy makers in relation to resource efficiency.	Van Ewijk et al. (2018)
Industrial Symbiosis Indicator Tool	Indicator detects variation of symbiosis over time and offers dynamic view of EIPs.	Supports managers as indicator detects variations using simple metrics and enables firms to actively manage process to higher levels of IS.	Felicio et al. 2016). See also: Mantese & Amaral, (2017)
Event-based Analytic Tools Tool	Demonstrates co evolution processes in IS networks and impact of orchestration by policy makers.	Helps in determining policy implementation as important dynamic for effective governmental facilitation of EIPs and CEIPs.	Jiao et al. (2018)
Hybrid Physical Input and Monetary Output (HPIMO) Model	Designed to simulate alternative IS patterns at city level; superior to material flow analysis as enhances modeling of material and economic flows/ reflects more accurately interconnections between sectors.	Allows managers to develop IS scenarios related to waste materials, recycling and revalorisation.	Dong et al. (2013)

Materials Flow Analysis (MFA) Tool	Material flow analysis (MFA) allows input and output flows to be mapped over each process life cycle.	Enables managers to identify resources, i.e. energy, water and waste for potential synergies.	Sharib & Halog (2017)
Integrated AHP (IAHP) Model	"Multi-objective optimisation approach that uses numerical representations to rank preferences of each participating plant on predefined criteria for building an EIP" p. 1268.	Model is designed to provide balanced solution within a set of constraints, e.g. "economic performance, environmental impact, connectivity and network reliability" p. 1268.	Leong et al. (2017)
Weighted Goal Programming Model	System architecture design tool to model collaborative networks with emphasis on by-product exchange.	Model helps users meet economic and environmental objectives when establishing EIP connections.	Tiu & Cruz (2017)
By-product Exchange Network (BEN) Model	System architecture design tool to model collaboration platforms for enabling industrial Symbiosis with focus on by-product exchange networks.	Model acts as decision support tool for managers to evaluate economic viability of symbiotic interactions.	Raabe et al. (2017)
Linear Programming (LP) Cooperative Game Model	Optimises costs and benefits allocation to provide fair share to players within EIPs.	Allows managers to allocate fair benefits that accrue from synergies in an EIP.	Tan et al. (2016)
Quantitative Model for Optimal Location and Scales for Plants in IS	Model analyses optimal locations/ scales for power plants (CO_2 emissions/ reduction targets/ demand scenarios.	Provides mathematical method to plan development of IS clusters.	Shiraki et al. (2016)
Industrial Symbiotic Network Model (ABM)	Model simulates emergence/ operations of self-organized IS networks in multiple scenarios.	Helps practitioners to understand importance of information-sharing and consider if sensitive information is truly sensitive or is non-sensitive, in order to facilitate exchanges.	Fraccascia & Yazan (2018)
Multi-agent Based Simulation Model	ABM model that highlights critical socioeconomic and social policies, e.g. waste charge policies/ market	Helpful for decision makers to design/ implement improvements/ optimise behaviours of management,	Dong, Wang, Scipioni, Park & Ren (2018)

	measures to enhance benefits of waste treatment.	infrastructure, spatial location and economic/ environmental impacts.	
Agent-based Model of Self-Organized IS	Models self-organised IS developments, e.g. simulating social elements, i.e., social structures, trust and knowledge diffusion through IS.	Model enables trust as attribute to be modelled using social links between plants, and to include it in processes of knowledge diffusion and synergy creation.	Ghali, Frayret & Ahabchane (2017) See also: Yazan et al. (2018)
Integrated Stability Analysis Method	Used to evaluate stability of performance in IS networks.	Helps managers manage stability of industrial symbiosis networks and encourage new synergistic activities.	Wang et al. (2017)
Agent Based Method for Measuring ISN Resilience	Specific quantitative method for "measurement of ISN resilience, based on assessment of firm, and network diversity and waste ubiquity – three indices that are important for resilience in ISNs" p. 149.	Useful in both designing resilient ISNs and identifying vulnerable ISNs with high dependencies.	Fraccascia, Giannoccaro & Albino (2017)
LCA Modelling Method	Quantitative method for calculating exchanges of materials and benefits in complex systems. Multiple scenarios produced to test sensitivity. Input and sharing of data enabled by modelling process.	Method allows benefits to be partitioned between firms taking part in network.	Martin, (2015)
LCA Method for Steel Production	Provides holistic view of process impacts/ information on reusable by-products for use as secondary raw materials.	Helps management develop baseline in order to provide starting point for development of symbiotic waste reutilization scenarios.	Renzulli et al. (2016)
LCA Method for Green Chemistry	LCA to evaluate different options for implementing industrial symbiosis solutions and ensuring green chemistry options respond to requirements of reducing environmental burdens in all life cycle stages.	LCA helps support eco innovation strategies by identifying possible improvements.	Secchi et al. (2016)

LCA Method for Environmental Evaluation of Industry Cluster Strategies	Method for full value stream life cycle assessment (LCA) for environmental evaluation of industry cluster strategies.	Provides assessment method for upstream and on-site activities/ estimates CO2 reductions in downstream processes and develop effective IS strategies.	Røyne et al. (2017)
LCA Hybrid with Land-use Area Metrics Method	LCA combined with land-use area metrics method as hybrid method to analyse environmental effects in order to develop management strategies.	Provides broader analytical results than LCA alone to enable more effective strategies to be developed.	Adiansyah et al. (2017)
Hybrid Physical Input and Monetary Output (HPIMO) Model	Tool designed to simulate alternative IS patterns at urban level; superior to material flow analysis as enhances modeling of material and economic flows/ reflects more accurately interconnections between sectors.	Allows managers to develop IS scenarios related to waste materials, recycling and revalorisation.	Dong et al. (2013)
Emergy-based Hybrid Method	Method uses integrated evaluation approach combining emergy analysis, "technology (IPAT formula) and index decomposition analysis (IDA) methods" to investigate impact factors of IS in IPs p. 132.	Facilitates self-checking of problems and development of feasible targets. Helps policy makers recognise key barriers to IS and develop mitigation strategies.	Zhe et al. (2016) For emergy based methods see also: Fan et al. 2017; Liu et al 2018; Ohnishi et al. 2017; Pan et al. 2016; Ren et al. 2016; Saladini et al. 2018; Sun et al. 2017b; Wu, J. et al. 2017; Wu, Y. et al (2018)
Multiobjective Mathematical Programming Model	Model is designed for "optimisation of by-product flows, synergy configurations and investment decisions in eco-industrial networks" p. 1284.	Supports companies and network facilitators with method to integrate and analysis of "economic and environmental issues, e.g. through sensitivity analysis of selling price of waste/minimum processing capacity of equipment" p.1284.	Maillé & Frayret (2016)
Advanced Mathematical Model for EIPs	Multilevel modelling tool for optimisation of an EIP.	Uses multilevel framework from unit to industrial network with advanced mathematical modelling to enable every level's activities to be catalogued.	Pan et al. (2016)

Logarithmic Mean Divisia Index Model	Model used to understand future low carbon scenarios using analysis "applied to carbon emissions in a decomposition of time and space sequence" p. 156.	Allows long term analysis of carbon emission decomposition to evaluate potential of low carbon development, promote policies regarding "regional sustainable development and construction of eco-industry (as business as usual) scenarios." p. 156.	Liu et al. (2016) See also Sumabat et al. (2016)
Adjusted Raw Material Consumption (ARMC) Method	Method provides wider "scope for calculating resource consumption including upstream (mining/refining) of primary resources; reveals actual resource consumption structures/ determines key resource for holistic improvements to resource productivity" p. 42.	Provides management method for use in IPs to improve resource productivity.	Hu et al. (2017)

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