European
Commission

Cooperation fostering industrial symbiosis: market potential, good practice and policy actions

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate C – Industrial Transformation and Advanced Value Chains
Unit C1 – Clean Technologies and products
Contact: Anestis Filopoulos
E-mail: GROW-C1@ec.europa.eu

European Commission
B-1049 Brussels

Cooperation fostering industrial symbiosis market potential, good practice and policy actions

Final report

Main authors:
Teresa Domenech – University College London
Asel Doranova, Laura Roman – Technopolis Group
Matthew Smith, Irati Artola – Trinomics

Further contributors to data collection through interviews, data analysis, case studies or literature review:
Elmer Rietveld, Roald Suurs - TNO
Ruslan Zhechkov, Nathan Kably – Technopolis Group
Peter Laybourn, Rachel Lombardi – International Synergies
Nino Jordan, Dimitrios Panayotopoulos-Tsiros – University College London

We would like to also acknowledge the engagement of over 60 stakeholders in interviews, the targeted survey and the three focus groups, as well as over 60 stakeholders participating in the final workshop organised within the context of the study.

LEGAL NOTICE

Luxembourg: Publications Office of the European Union, 2018

ISBN number 978-92-79-74679-6
doi:number 10.2873/346873

Printed in Belgium

Table of Contents

Table of Figures

List of Tables

List of abbreviations

BAT	Best Available Technologies
BSI	British Standardisation Institution
C&D	Construction and demolition
C&DW	Construction and demolition waste
CE	Circular economy
CEN	European Committee for Standardisation
CHP	Combined heat and power
CO2e	Carbon dioxide equivalent
CWA	European Committee for Standardisation (CEN) Workshop Agreement
EC	European Commission
EEA	European Environmental Agency
EPR	Extender Producer Responsibility
ERDF	European Regional Development Fund
ESIF	European Structural and Investment Funds
EU28	European Union of 28 Member States
FISS	Finnish Industrial Symbiosis System
GHG	Greenhouse gases
GIS	Geographic Information System
GPP	Green Public Procurement
Horizon2020	European Framework Programme for Research, Development and Innovation
INTERREG	European Programme for Territorial Cooperation
IPPC	Integrated pollution prevention and control
IS	Industrial symbiosis
ISO	International Organisation for Standardisation
LCA	Life-cycle assessment
MS	Member States
MSW	Municipal solid waste
NISP	National Industrial Symbiosis Programme
ROI	Return on investment
VAT	Value Added Tax
UK	United Kingdom
WEEE	Waste Electrical and Electronic Equipment
WFD	Waste Framework Directive

Executive summary

Industrial symbiosis (IS) is a systems approach to a more sustainable and integrated industrial system, which identifies business opportunities that leverage underutilised resources (such as materials, energy, water, capacity, expertise, assets etc.) (Lombardi & Laybourn, 2012). IS involves organisations operating in different sectors of activity that engage in mutually beneficial transactions to reuse waste and by-products, finding innovative ways to source inputs and optimising the value of the residues of their processes.

In this study, the **types of industrial symbiosis** that are being analysed include two major groups: **1) self-organised** activity, emerging as the result of direct interaction among industrial actors, without any top-down coordination; **2) managed networks**, those that have a third party intermediary that coordinates the activity (Baas 2011). Two distinct **types of managed networks** exist:

- **2a) facilitated networks**, working with existing companies to raise awareness of IS and foster activity and
- **2b) planned networks**, where the networks are formed following a central plan or vision that includes attracting new businesses to purpose-built developments, generally offering shared infrastructures and services.

Industrial Symbiosis 'synergies' are transactions or activities of acquiring waste resources between one company generating the waste and another company or organisation integrating them as inputs into the production process.

Industrial Symbiosis networks contain different industrial actors belonging to different sectors of activity that engage in mutually beneficial transactions of waste and by-products (such as materials, energy, water, capacity, expertise, assets etc).

IS has been seen as a solution to enhance environmental sustainability and achieve economic benefits at the same time. However, while there are cases of successful implementation of industrial symbiosis, there is still little overview of the market for industrial symbiosis, and the scale at which it has been adopted. Moreover, the importance of intermediary bodies as facilitators of industrial symbiosis has only just begun to be considered as an important factor for the success of industrial symbiosis initiatives.

In this study, we aim to provide an overview of the market potential for industrial symbiosis and a mapping of the major initiatives that have been implemented in Europe and their results.

Moreover, based on findings from the literature review, a survey with facilitators of IS, 28 interviews and three focus groups carried out with 20 practitioners, the study aims to answer three main research tasks:

A. Identify **key success factors as well as issues hindering the development of industrial symbiosis:**
   - Develop a typology of industrial symbiosis to facilitate analysis
   - Understand the roles of coordination nodes in industrial symbiosis
   - Assess alternative coordination mechanisms and their impact on industrial symbiosis performance (why typology of facilitation and support services provide better benefits)

B. **Assess policy actions that support industrial symbiosis at different levels** (local, regional, national, European):
   - Identify specific policy instruments to promote and foster industrial symbiosis

- Identify general framework conditions that favour the development of industrial symbiosis
- Identify policy implementation routes (policy mixes) and ways to promote stakeholder engagement

C. Assess the **feasibility and options of EU-level interventions to contribute to scaling up and promoting IS initiatives** across Europe or an EU-level trading platform for secondary raw materials:

- Investigate ways to promote collaboration between coordination nodes at different levels (local, regional, national, European)
- Assess the need for the creation of an EU-level coordination platform or trading platform, as well as enablers and alternative structures.

In **Chapter 1** we provide an overview of the definition of IS used in this study, as well as the difference between IS and recycling practices. The literature review on the typologies and emergence of networks, as well as on the organisational structure of IS initiatives aims to provide background knowledge on the key concepts that are used throughout the study.

Chapter 2 focuses on mapping the existing self-organised and facilitated IS initiatives in Europe, and their key characteristics. The mapping indicates pockets of IS activity all across Europe, although varying in nature, resources transacted and scale. Importantly, the majority of the self-organised networks are located in Northern Europe, in countries like Sweden, Denmark or Finland but with examples in other traditional industrial clusters. An example of large scale facilitated networks has been developed in the United Kingdom (UK), based on the National Industrial Symbiosis Programme (NISP), which received investment from the UK government in 2007-2013 and has shown significant environmental and economic returns. After the disruption in public funding for the NISP programme, activities have resumed at regional level, depending on local capabilities. The longest-standing facilitated IS network is the Industrial Symbiosis Service in Northern Ireland, which has followed the NISP model. Outside the UK, there are examples of facilitation structures in Finland, Denmark, Belgium, Italy and France, as well as in Central and Eastern Europe (Hungary, Romania, Poland, Slovenia). While they exhibit large variation in terms of focus and geographical scope, their approach to facilitation has been based on adapting several elements of the UK NISP model.

After reviewing the state of the art in terms of assessment frameworks used for evaluating the performance of industrial symbiosis in **Chapter 3**, a key finding is that **very few IS facilitation initiatives track their results** in a consistent manner, which makes it hard to provide accurate assessments of their performance. To address this gap, in **Chapter 4** we provide a cross-comparison of the **results of a selection of facilitated and self-organised IS networks**, for which data exist and are comparable. Data sources are self-reported benefits in publicly available reports and data gathered during the survey and interviews with representatives of the IS initiatives. Given the lack of independent verification, the quantitative results provide only an indicative basis for assessing the performance of existing IS facilitated initiatives. Further research is needed to: 1) define harmonised frameworks for data gathering and reporting of impact and 2) enhance the cross-comparison basis to derive performance benchmarks for IS activity, especially in the case of facilitated networks.

Despite data limitations, the assessment of facilitation in Europe has provided some interesting insights for the analysis of IS policy options. Firstly, facilitation programmes have varied substantially in terms of scope and scale. There are only a handful of networks that have operated for more than five years with the support of governmental funds, while there are many more examples of networks that have worked only for a limited period of time linked to specific funding streams. There is no evidence of operative fully commercial facilitation activity in Europe.

As noted above, one key problem to assess the performance of IS facilitation is the lack of harmonised frameworks for assessment and the very limited quantitative data reported by facilitators. For those initiatives for which there are comparable data, evidence suggests that IS facilitation achieved environmental objectives of landfill diversion and GHG savings at a relatively low cost and with some additional benefits for companies in terms of savings in raw materials, cost savings from landfill diversion, additional sales and generation of new areas of revenue. However, there is little understanding about the transactional costs associated with the realisation of IS synergies in terms of time, expertise and investment (though it may be safely assumed the synergies wouldn't have proceeded without a net benefit). The analysis also suggests that some IS projects may take a long time from inception (idea stage) to realisation, which may also impact the way in which benefits are distributed temporally and may also create a disincentive for companies that need short term solutions. The study has also explored the role of PPPs in addressing some of these hurdles.

Comparing the performance of self-organised and facilitated activities is extremely difficult, as the scale, scope and types of transactions differ substantially. The analysis has identified successful examples of self-organised IS activity in Europe. These are generally quite localised and initially driven by a collective problem or opportunity. There are also examples of IS activities at the industrial park level, sometimes led by an anchoring activity. Self-organised activity generally develops over a long period of time and is the result of a number of different factors including scarcity of a specific resource, or pressures from the regulatory framework or the supply chain.

The results of the market analysis are presented in **Chapter 5**. The market analysis took two analysis routes. Firstly, by analysing the potential savings that could be achieved by diverting waste from landfill through IS, the study shows that the absolute maximum market potential of IS could reach €72.7b through cost savings due to landfill diversion (e.g. through landfill costs avoidance). Secondly, from the point of view of generation of value, the market potential that could be generated by transactions of secondary materials is estimated at between €6.9b (in the low estimate scenario) and €12.9b (in the high estimate scenario). In both cases, estimations also include conventional recycling solutions, which may fall outside the scope of IS. The estimate of market potential focuses on the residual value of waste. However, due to data limitations it does not account for the upstream market potential of resources not becoming waste, such as 'by-products' transactions and reuse/recirculation of materials. Future analysis should try to cover this gap. Better monitoring processes of data for resources classified as 'by-products' and those that reach EoW status in MS are required to provide a more comprehensive picture of market potential for IS.

In order to understand why this market potential remains under-utilised, **Chapter 6** provides a snapshot of system and market failures that IS initiatives (individual synergies and coordination) face, which hamper their economic viability and scaling-up. The study suggests that IS models experience market failures due to the companies' perceived risk and uncertainties regarding the benefits of IS synergies. The initiation of IS projects is in many cases accompanied by costs that companies are not always prepared to bear. In particular, the lack of internalising the costs of externalities such as waste may reduce the viability of IS practices, due to the lack of a clear business case (e.g. from expensive landfilling). This may depend from a number of structural and contextual factors, such as the level of the landfill charges in the country, which differ substantitally across the EU. Learning costs associated with IS explain why some businesses may feel more comfortable with business-as-usual practices in dealing with waste and not open to invest in changes. Information asymmetries are also common barriers to IS, as potential buyer companies have limited access to information about available secondary resource streams, their chemical composition and properties or specifications of the materials. In addition, the profit margins involved are not always attractive and predictable enough to make a business case for joining an IS activity. Prices for primary raw materials, which may not have internalised externalities of extraction and transformation, may not be conducive to the competitiveness of the IS activity.

System failures identified by survey respondents and interviewees were related to the lack of capabilities to coordinate and negotiate synergies, and find matching conditions. Often companies are unaware of the potential associated with IS practices or find it difficult to change business as usual practices. In most cases, IS synergies may need infrastructure and logistical arrangements, which require time and investment to organise. Coordination activities by a third party rely largely on governmental support, as marginal value is generally low.

Given the identified market and system failures, **Chapter 7** offers an overview of policies and policy options that have been mapped for supporting IS, including direct support through facilitation of IS, as well as indirect support through a combination of instruments to support adequate framework conditions for IS activity. The latter include regulatory measures (such as hamonisation of regulation and adjustments to the implementation of the concepts of 'by-products' and 'End-of-Waste' criteria), economic instruments (such as landfill taxes) and voluntary or self-regulation instruments (such as standardisation of secondary materials; protocols; harmonised reporting).

Several member states, such as the UK, Finland, France, Denmark or regions such as Flanders in Belgium, have experience in supporting IS facilitation directly, though national or regional facilitation programmes. The policy approach has been mainly related to supporting the 'connection' stages of IS implementation, including organisation of matchmaking events, collection of data on resource streams and identification of IS potential. In some cases it has also included hands-on technical support for the implementation of identified synergies. Scope, size and performance of facilitation activities vary considerably across programmes. Results seem to suggest that facilitation requires in most cases public support at least in the first phases of the network development. Nevertheless, exploring mixed options, by accompanying private financing of such activities with matching public funding, is an approach worth considering. In fact, there is evidence of self-organised activity supported by Public Private Parnerships (PPP). Predictability and long-term public commitment to supporting IS have also been considered necessary to incentivise the private sector engagement in IS activities.

One key finding of this study is that **the success of IS initiatives is largely dependent on the policy environment.** The more incentives there are for waste diversion from landfill, and for alternatives to landfilling and incineration (e.g through economic incentives for reuse of materials or landfill and incineration bans), the larger the opportunity is for engaging in IS practices.

Importantly, regulatory uncertainty related to the status of secondary materials (waste versus product) has been one of the major issues that deter companies and institutional investors from supporting IS endeavours. Therefore, improving the clarity and harmonising interpretation of waste regulation and in particular **the application of the concepts of by-product and 'End of Waste' criteria** as well as providing further **guidance on the distinction between by-products/ no-waste and waste** and the harmonising transposition of these concepts in Member States are key actions to undertake in order to make IS transactions more attractive to companies.

The stakeholders' consultation has emphasised the role the EU has to play to promote IS. One key priority is to address existing regulatory barriers and improve framework conditions to support IS. This is, partly, being tackled through the revision of the EU waste legislation as proposed by the Commission in 2015, which is up for final adoption by the European Parliament and the Council at the moment of writing this report. The EU could also help to set up adequate conditions for secondary material markets and providing coaching and assistance to MS with limited technical capacity to adequately transpose and implement key regulatory instruments.

Overall, the study results suggest that there may be a role for facilitation of IS to accelerate the take-up of IS practices, through addressing some of the existing barriers such as communicational, regulatory or technical barriers; however, the success of IS facilitation depends on the existence of a suitable regulatory environment.

Undertaking or promotion of facilitated activities at the EU level, for example through hands-on coordination of IS synergies through an EU-level trading platform, is considered less necessary by stakeholders, as the national, regional and local levels seem more appropriate for direct facilitation. Rather, the EU may have a role to play through supporting governments in defining or adopting IS policies and regional or local stakeholders in implementing IS through knowledge and capacity building.

Based on the feedback of the stakeholders, three main options have been assessed for **the configuration of an EU-level platform** offering specific services to IS stakeholders:

Option 1: an **EU-level "Platform of Platforms"** that would focus on enhancing the knowledge base for industrial symbiosis and facilitate knowledge sharing.

Option 2: a **trading platform for cross-boundary synergies at the EU level**, which was less preferred by stakeholders, due to several limitations imposed by the transport of waste and lack of harmonisation of by-product and end-of-waste status across countries.

Option 3: a centre of excellence for IS, which would actively 1) contribute to enhancing the knowledge base for IS in Europe ; 2) develop capacity in the area of IS, targeted at IS practioners and policy-makers, and 3) be a first point of contact between the EU and key stakeholders in the area of IS. This option builds on the 'platform of platforms' option to offer additional functions such as coaching and education and active dissemination of best practices.

Key policy recommendations derived from the study are listed below and can be classified into the following key areas:

A. Definition of suitable framework conditions to drive the adoption of IS solutions, including addressing current barriers to IS implementation;

B. Development of a knowledge base and harmonised frameworks for assessment of IS;

D. Planning instruments

C. Finance and strategic investment in IS

E. Support of actions encouraging spontaneous networking and bottom-up approaches.

The key policy measures recommended are listed in the following pages.

A. IMPROVE FRAMEWORK CONDITIONS FOR IS IN EUROPE

1. Increase cost of landfill and incineration to promote reutilisation of materials (potentially through exploring the possibility of raising landfill taxes).

2. Introduce landfill bans and adequate implementation through standardised acceptance.

3. Clarify the concept of 'by-product' and promote harmonised transposition across MS.

4. Consider extending the scope of 'by-product' to residuals with a direct application in other sectors of activity with no or very reduced market value.

5. Clarify procedure for 'End of Waste' criteria to: 1) harmonise process across different regions and MS; 2) reduce the administrative burden; 3) provide coaching and detailed guidance for countries/regions with low technical capability; 4) clarify status of 'End of Waste' criteria across borders.

6. Create a register of EoW and data reporting and monitoring guidelines so that information on type and volume of resources transactioned under these concepts ('End of Waste' and by-products) is available for the EU, contributing to clearer identification of areas of potential for IS. This could be done through an online platform at EU level to help users review materials that have obtained the EoW status in other MS.

7. Facilitate transport of waste across borders for IS utilisation through streamlined administrative processes (i.e. similar procedure as 'End of Waste') that ensure safety but also optimal use of resources.

8. Clarify standards for by-products to ensure performance and quality of secondary raw materials and detailed specifications.

9. Introduce incentives for the use of secondary materials.

- This can be done through economic instruments but also through regulatory instruments such as design standards that set minimum requirements for use of secondary materials (introduction of IS principles in the Ecodesign Directive).
- This can be justified as a measure to internalise negative externalities associated with extraction and transformation of primary raw materials, when supported by detailed LCA analysis.

10. Tax border adjustments and introduction of resource taxes may also be necessary to ensure internalisation of externalities for imports to the EU, as some of the noted barriers refer to the difficulty of secondary materials to compete with cheap primary resources.

11. Introduce IS principles for optimisation/reutilisation of materials, water, energy and heat in large developments through planning and building regulations.

12. Add IS principles to GPP policies (particularly relevant for infrastructure projects)

13. Promote supply chain approaches that recognise the value of IS and collective solutions (e.g. treatment and recovery facilities shared by a number of companies, or a circular supply chains voluntary protocol).

B. IMPROVE THE KNOWLEDGE BASE FOR IS IN EUROPE

14. Enhance the assessment and knowledge base for industrial symbiosis in Europe by:

- Creating a database of IS opportunities, including identification of waste streams with potential, key sectors, technologies and re-purposers. The database should be presented integrated on an online geographical tool.
- Utilising current information (related mainly to IPPC activities) to create a knowledge data-base of waste and material flows using a GIS supported downloadable software.
- Maintaining a monitored database of impact achieved by IS networks in Europe.
- Identifying market potential for specific waste streams as well as levers and barriers for reutilisation (including technological, logistical, infrastructural and economic).

C. PLANNING INSTRUMENTS

15. Promote introduction of IS principles in IPPC procedures and activity licencing to promote better reutilisation of materials, water, energy and heat considering IS opportunities among co-located activities at the regional level.

- Guidelines for introducing IS principles in IPPC procedures
- Offer coaching to national/regional authorities in the implementation process, especially those with low technical capabilities.

16. Introduce IS principles in strategic planning and economic development plans at the local and regional level to:

    a. identify potential for optimisation of material use/reutilisation;

    b. promote heat exchange networks;

    c. identify low carbon sources of energy and

    d. identify opportunities for eco-innovation and inward investment.

- Map resource flows to understand opportunities to recover material, energy, water and heat, using the "accounting" standards from the knowledge base
- Map existing and desirable infrastructure to facilitate synergies. Attention should be paid to examples in the online IS database where old pipelines, trajectories and water management systems were revitalised for IS solutions.

D. FINANCE AND STRATEGIC INVESTMENT

17. Provide (new) financial resources for facilitation of IS to overcome informational and transactional barriers (market failures as well as regulatory or technical barriers). They may also contribute to nurture social networks to facilitate implementation.

18. Develop financial instruments that are more suited for the risk profile of initiatives developing IS or 'circular value chains' projects together with the Circular Economy Finance Support Platform.

19. Support exploration of IS opportunities through R&D by integrating IS principles in priority areas of innovation.

E. OTHER INSTRUMENTS TO PROMOTE SELF-ORGANISED ACTIVITY AND BOTTOM UP APPROACHES

20. Developing harmonised standards and assessment frameworks to measure impact from IS activity. This could not only allow for better comparison across initiatives (and thus enhancing knowledge of IS potential) but would also contribute to best practice sharing and dissemination (e.g. International Synergies, SIST, BSI and CEN has started a process for a CEN Workshop Agreement (CWA) which is an initial phase in progressing towards defining a standard on IS, initially at a European level and possibly leading to a full ISO)

21. Connected to the point above, creating voluntary approaches for reporting IS activity both for industries and regions could create incentives for companies to engage in IS activity which could link to corporate responsibility

22. Self-regulatory approaches and voluntary agreements could also be negotiated between industrial partners to identify opportunities to optimise the use of resources through IS type of approaches while enhancing the image of a region or area and attracting forward-thinking companies that may have complementary needs

The following tables provide an illustration of the recommended policy measures and the suggested level of governance at which they could be applied.

Framework conditions for IS in Europe	EU	National	Regional	Local
Increase cost of landfill and incineration to promote reutilisation of materials (potentially through exploring the possibility of raising landfill taxes).	√	√	√	√
Introduce landfill bans and adequate implementation through standardised acceptance.	√	√	√	
Encourage transposition and adoption of the (legal process of authorisation) of the concept of "by-product" and reduce complexity of its application across borders	√	√		
Consider the application of the concept of 'by-product' or other legal concept for those resources which have a direct application but have a very small (close to zero) market value	√			
Clarify procedure for 'End of Waste' criteria to: 1) harmonise process across different regions and MS; 2) reduce the admin burden;	√	√		

Framework conditions for IS in Europe	EU	National	Regional	Local
3) provide coaching and detailed guidance for countries/regions with low technical capability; 4) clarify status of 'End of Waste' criteria across borders				
Create a register of EoW and data reporting and monitoring guidelines so that information on type and volume of resources transactioned under these concepts is available for the EU, contributing to clearer identification of areas of potential for IS. This could be done through an online platform at EU level to help users review materials that have obtained the EoW status in other MS.	√			
Facilitate transport of waste across borders for IS utilisation through streamlined admin processes (i.e. similar procedure as 'End of Waste') that ensure safety but also optimal use of resources	√	√		
Clarify standards for by-products to ensure performance and quality of secondary raw materials and detailed specifications	√	√		
Introduce incentives for the use of secondary materials. This can be done through economic instruments but also through regulatory instruments such as design standards that set minimum requirements for use of secondary materials (introduction of IS principles in Ecodesign Directive). This can be justified as a measure to internalise negative externalities associated with extraction and transformation of primary raw materials, when supported by detailed LCA analysis.	√	√		
Tax border adjustments and introducing resource taxes may also be necessary to ensure internalisation of externalities for imports to the EU, as some of the noted barriers refer to the difficulty of secondary materials to compete with cheap primary resources.	√	√		
Add IS principles to GPP policies (particularly relevant for infrastructure projects)	√	√	√	√
Promote supply chain approaches that recognise the value of IS and collective solutions (e.g. treatment and recovery facilities shared by a number of companies or a circular supply chains voluntary protocol)		√	√	√

Knowledge base for IS in Europe	EU	National	Regional	Local
Create a database of IS opportunities, including identification of waste streams with potential, key sectors, technologies and re-purposes. The database should be presented integrated in an online geographical tool.	√	√		
Utilise current information (related mainly to IPPC activities) to create a knowledge database of waste and material flows using a GIS supported downloadable software.	√	√		
Maintain a monitored database of impact achieved by IS networks in Europe.	√	√		
Identify market potential for specific waste streams as well as levers and barriers for reutilisation (including technological, logistic, infrastructural and economic).	√			

Planning instruments	EU	National	Regional	Local
Planning instruments A: Promote introduction of IS principles in IPPC procedures and activity licencing to promote better reutilisation of materials, water, energy and heat considering IS opportunities among co-located activities at the regional level				
Guidelines for introducing IS principles in IPPC procedures	√	√	√	√
Offer coaching to national/regional authorities in the implementation process, especially those with low technical capabilities	√			
Planning instruments B: Introduce IS principles in strategic planning and economic development plans at the local and regional level to: a) identify potential for optimisation of material use/ reutilisation; b) promote heat exchange networks; c) identify low carbon sources of energy and d) identify opportunities for eco-innovation and inward investment.				
Map resource flows to understand opportunities to recover material, energy, water and heat, using the "accounting" standards from the knowledge base		√	√	√
Map existing and desirable infrastructure to facilitate synergies. Attention should be paid to examples in the online IS database where old pipelines, trajectories and water management systems were revitalised for IS solutions.		√	√	√
Introduce IS principles for optimisation/reutilisation of materials, water, energy and heat in large developments through planning and building regulations	√	√	√	√
Self-regulatory approaches and voluntary agreements could also be negotiated between industrial partners to identify opportunities to optimise the use of resources through IS type of approaches while enhancing the image	√	√	√	

Planning instruments	EU	National	Regional	Local
of a region or area and attracting forward-thinking companies that may have complementary needs				

Finance and strategic investment	EU	National	Regional	Local
Provide (new) financial resources for facilitation of IS to overcome informational and transactional barriers (market failures as well as regulatory or technical barriers). They may also contribute to nurture social networks to facilitate implementation.	√	√	√	√
Develop financial instruments that are more suited for the risk profile of initiatives developing IS or 'circular value chains' projects together with the Circular Economy Finance Support Platform.	√			
Support exploration of IS opportunities through R&D by integrating IS principles in priority areas of innovation.	√	√		

Other bottom-up approaches to promote IS	EU	National	Regional	Local
Developing harmonised standards and assessment frameworks to measure impact from IS programmes that allows for better comparison across initiatives and best practice methodologies through voluntary protocols (e.g. BSI and CEN has started a process for a CEN Workshop Agreement (CWA) which is an initial phase in progressing towards defining a standard on IS, initially at the European level and possibly leading to a full ISO)	√	√		
Creating voluntary approaches for reporting of IS activity both for industries and regions that contribute to better communication and awareness	√	√		

1. INTRODUCTION

1.1. Definition of Industrial Symbiosis (IS)

Industrial symbiosis (IS) is a systems approach to a more sustainable and integrated industrial system, which identifies business opportunities that leverage underutilised resources (such as materials, energy, water, capacity, expertise, assets etc.) (Lombardi & Laybourn, 2012). IS involves organisations operating in different sectors of activity that engage in mutually beneficial transactions to reuse waste and by-products, finding innovative ways to source inputs and optimise the value of the residues of their processes, for instance by using waste or by-products from one activity as an input for another activity.

There is some confusion generated by the diversity of terminology surrounding IS due to the lack of a standardised and internationally accepted methodology for industrial symbiosis (Van Berkel, 2006). That is why we formulate some **elements, which we consider key in characterising industrial symbiosis:**

- ✓ It may involve different industry actors, belonging to different sectors of activity. As with Porter's cluster theory, it also involves governmental and other institutions, including universities and trade associations for example.
- ✓ It may involve transactions not only of material resources but also energy and water and other resources such as space, knowledge, expertise, capacity and logistics.
- ✓ It involves a systemic view of how industrial systems work.
- ✓ IS includes both bilateral (organisation to organisation) and multilateral (multiple organisations involved) transactions.
- ✓ Transactions may happen within the boundaries1 of the network or beyond them and may involve both current network-members and new participants2 (main criteria being valorisation of the resources)
- ✓ These transactions can be assimilated in most, if not all, cases to market transactions. It is hypothesized that, in some cases, they may transcend mere market exchange and involve different degrees of cooperation.
- ✓ The identification of collaboration potential takes place through networking, whereby stakeholders interact to find mutually beneficial solutions.
- ✓ The environmental and economic outcomes may surpass the outcomes that the individual organisations would obtain by acting individually so that there is additional benefit associated with the collaboration.
- ✓ Resources, water and energy may be optimised through cooperation, which goes hand in hand with reducing the environmental impacts of the IS participants' activities.
- ✓ Generally, IS participants prioritise the improvement of economic impacts or profitability in their own organisation in order to justify their participation in IS.

Physical movements, including material, energy and water, tend to be at the core of IS, but aspects such as exchange of knowledge, expertise, capacity and logistics are also important contributors to the economic and environmental advantages of IS. Chertow (2007) considers three primary opportunities for industrial symbiosis

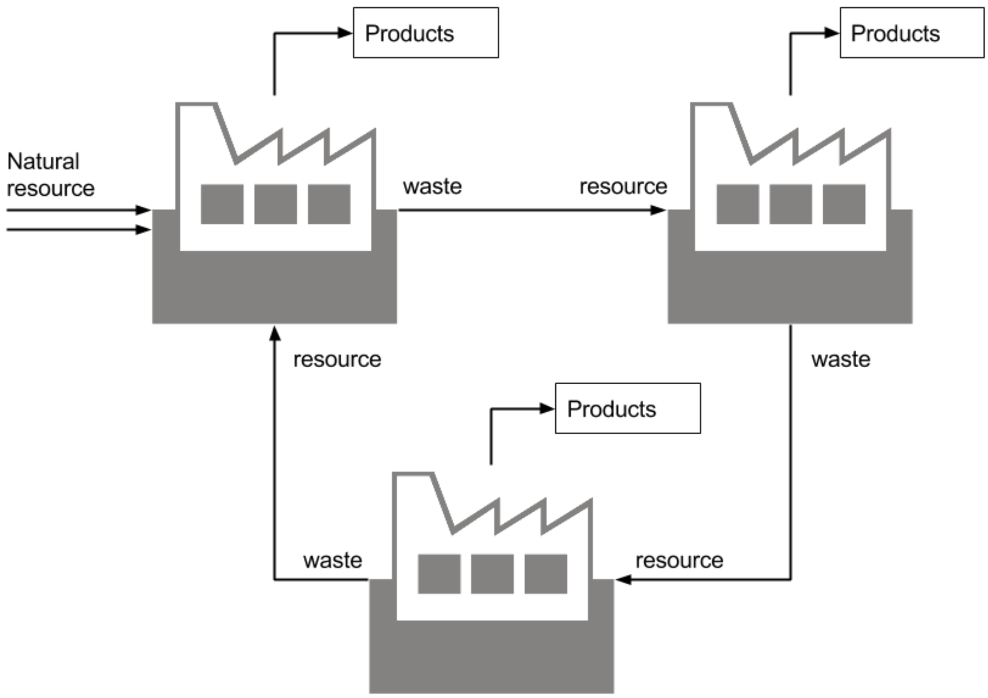
[1] Boundaries of a network may be flexible and defined by material flows rather than by administrative/membership status.

[2] Please note that informal networks may not have members as such. The status of member is achieved through engagement in synergies.

resource exchange: 1) by-product reuse; 2) utility sharing and 3) joint provision of services.

Our working definition of industrial symbiosis involves transactions involving material, water and energy as the core of network exchanges (Domenech and Davies, 2011). In some cases, transactions involving physical resources will also involve expertise and knowledge transfer. It is also important to note that transactions of one type of resource may trigger collaboration in other areas, involving other types of resources, as learning and transactions costs may be reduced and further opportunities identified.

Figure 1 Illustration of an IS network



Source: authors

In summary, our **working definition of industrial symbiosis encompasses networks of different industrial actors belonging to different sectors of activity that, by collaboration and networking identify opportunities to keep physical resources in productive use for longer (rather than go to waste), thereby achieving a better system performance in the use of resources** (including materials, energy, water, technology and knowledge), resulting in beneficial environmental and economic outcomes.

1.2. Difference between IS and recycling

In line with the confusion surrounding the concept of industrial symbiosis, IS transactions are sometimes confused with common waste management practices. IS is not a specific approach for dealing with waste but rather a systems approach that aims to keep resources in productive use, and maintain or increase their value. **This includes not only materials, but also energy, waste heat, space and other intangible assessts**. IS focuses on **opportunities to reduce and reuse (i.e., working at the high end of the waste hierarchy), and to move waste**

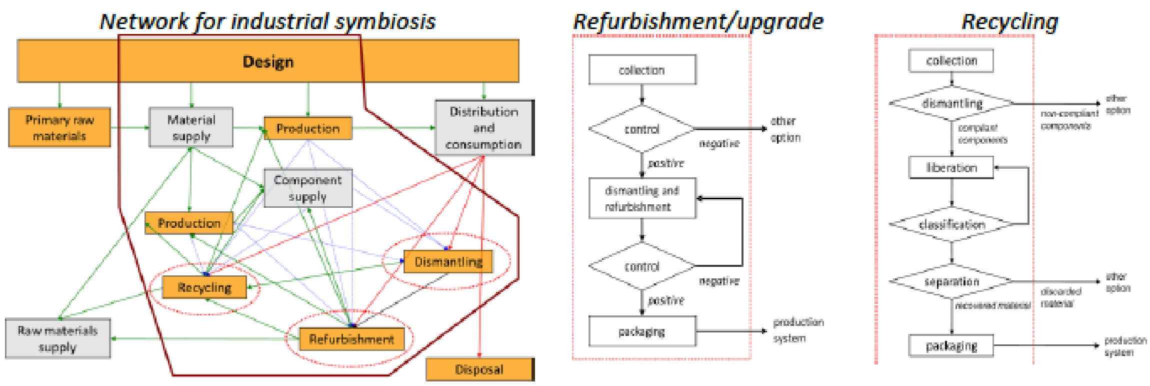
and residuals up the value chain by providing resource- and energy-saving alternatives to traditional management or recycling options.

From a system perspective, IS contributes to closing the loop of industrial processes by:

- Increasing the time the material/substance remains in the anthroposphere, before it becomes waste or is discharged to ecosystems
- Reducing the volume of waste sent to landfill or disposed of in nature, such as CO_2 emissions
- Increasing energy and material efficiency through further reuse and recycling of materials/substances/energy
- Creating jobs and business opportunities linked to alternative uses of existing waste streams
- Enabling demand-led innovation in support of the transition to a circular economy, by connecting businesses with the research community to address current technology/innovation needs.

As illustrated in the Figure below, the IS cooperation networks might need intermediate steps to prepare or treat the by-products of an industrial process before a transaction/synergy can take place. For these steps, upgrading the materials, cleaning, refurbishment or sometimes recycling might be necessary before the by-products or flows are consumed again. As such recycling can be a part of IS, but the concept of IS is much wider than just recycling. Policies directed towards landfill diversion and emissions reduction that assess systemically-best options to maintain integrity of resources and reduce wastage are within the remit of IS.

Figure 2 Differences between networks for IS (left) and the refurbishment/ upgrade (centre), and recyclyng (right) treatment



Source: La Marca, F. (2015).

1.3. Typologies of IS Networks

IS activity can generally be classified in two main groups: **1) self-organised activity**, emerging as the result of direct interaction among industrial actors; **2) managed networks**, those that have a third party intermediary who coordinates the activity. (Baas 2011) Two distinct types of managed networks exist: **2a) facilitated networks**, working with existing companies to raise awareness of IS and foster activity and **2b) planned networks**, where the networks are formed following a central plan or vision that includes attracting new businesses to purpose-built developments, generally offering shared infrastructures and services.

Industrial symbiosis networks can also be further characterised by their geographical scope and their organisational structure. Although there have been some examples of long-standing **self-organised networks** (i.e Kalundborg in Denmark was self-organised until 1989, achieving 10 synergistic relationships in that time [Schwarz & Steininger 1997]), evidence suggests that the geographical scope of these initiatives is necessarily limited due to informational and communicational barriers. Beyond the paradigmatic case of Kalundborg, there are otherself-organised IS networks operating in different regions in Europe but their geographical scope tends to be limited to the industrial area or region. Perhaps the best-known examples are the networks around the German industrial areas of Manheim and Heidelberg, which include a mix of chemical, automobile, cement and other construction material industries. In many instances, self-organised networks operate in areas where there is a concentration of industrial/manufacturing activity, including some large facilities and active policies to reduce or minimise landfill and other forms of pollution and impacts and improve waste management, which may include taxes and regulations but also voluntary agreements and business-led initiatives. Research on self-organised networks has tended to conclude that elements such as geographical proximity, trust and equity play a role in IS network development (Boons and Bass, 2010). Chertow (2007) observed that uncovering existing IS activity leads to an increase in said activity; this observation is borne out by the Kalundborg experience where 10 synergies self-organised between 1961 and1989 (before being 'uncovered') whereas a further 6 developed in the 5 years following. (Schwarz & Steininger 1997). This is evidence that one of the critical roles of coordination is raising awareness amongst industry.

Within **self-organised** networks (**1**), most successful examples come from "**anchor tenant**" **networks** (Lehtoranta, 2011), where a central actor plays a relevant role in the network coordination by providing a large number of potentially valuable by-products but also exercising de facto roles of coordination and connection between actors.

Facilitated networks (2a) involve a coordination node that acts as a change agent: (1) promoting awareness and engagement among industrial actors, (2) facilitating exchange of information and providing expertise and advice to overcome potential technological problems and (3) driving innovation to identify novel uses of resources (demand-led innovation). A successful facilitated network on a national scale is the National Industrial Symbiosis Programme (NISP) in the United Kingdom (UK); the same model has been adapted and adopted in 30 countries on six continents, including in Europe: Belgium, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania and Spain. Over the past 2-3 decades, a number of other facilitated networks have been developed in Europe. In many cases, the project has been the result of public-private partnerships and funding streams, which have included EU programmes (e.g. LIFE+ in Hungary and Romania). In the Netherlands, a facilitated network was established in 1994, initiated by the industry association Deltalinqs (Baas 2011). Facilitated networks may also be delivered using a top-down approach, such as the activity by the Republic of Korea's Ministry of Commerce, Industries and Resources: dedicated Eco-Industrial Park (EIP) centres were established in existing industrial parks (IPs) to identify and facilitate IS synergies for the companies in the industrial parks (Lombardi & Laybourn 2012, p.31).

Finally, **planned networks (2b)** generally apply to new developments that are designed with IS principles in mind . Planned initiatives have focused on maximizing IS opportunities in concretely-defined geographical areas and/or industrial estates, the so-called Eco-Industrial Parks (EIP). There are also examples of planned networks that are part of regeneration plans for existing industrial areas, where there is a certain level of intervention and central planning but things such as the mix of industries are generally given. Examples of planned networks can be found in countries such as the UK, USA, Portugal, South Korea and China (for new EIPs, to differentiate from their facilitated approach to existing IPs), although their success has been limited in attracting industry to co-locate for the express purpose of IS (Chertow 2007).

1.4. Patterns of emergence and evolution

When looking at the ways in which IS emerges, the literature has documented three main models (Paquin and Howard-Grenville, 2011) that align with the typology above: 1) self-organisation (Chertow 2007); 2) facilitation by third–parties, including individuals or organisations and 3) top-down planning, generally with a focus on eco-industrial parks.

Baas and Boons (2004) identified three key stages in the evolution of facilitated networks: regional efficiency, regional learning and sustainable industrial district. Each of the phases involves increasing the number of activities and the diversity of actors in order to address more holistic issues. Chertow and Ehrenfeld (2012) identified two key stages in self-organised networks: the "uncovering" of industrial symbiosis, which unveils pre-existing bilateral and multilateral exchanges and the potential benefits associated with them (as happened in Kalundborg in 1989); followed by an institutionalisation stage, that deepens collaboration, reciprocity and may lead to additional IS projects (again evidenced in Kalundborg, post-1989). Economic feasibility will continue to underpin each of the stages in all 3 system types (self-organised, facilitated and planned) that are not managed top-down.

Domenech and Davies (2010) identified **four key phases in the evolution of IS networks**: *emergence, probation, development and expansion*. The emergent phase can occur though self-organised business-to-business transactions or through facilitation. Each phase involves more complex cooperation and entails different challenges in term of network coordination.

Paquin and Howard-Grenville (2011) suggest that IS evolution is mediated through the development of shared norms that intensify the scope of cooperation, through "embeddedness". The concept has been used to explain why IS has developed into complex networks in some contexts while it is has been difficult to replicate in others (Ashton, 2008; Domenech and Davies, 2011; Boons and Howard-Grenville, 2009). The term embeddedness (Uzzi, 1996; Granovetter, 1985) refers in the field of IS to the development of tacit norms and structural ties that underpin resource/material transactions.

Paquin and Howard Grenvillen (2011) go on to differentiate between **serendipitous and goal-directed network processes** in IS development. **Serendipitous processes** can generally be observed in self-organised networks. In these cases, network benefits and economic drivers are strong and firms have easy access to one another and cooperate to create value. The authors point out that in these types of networks, the pace of development is slow and generally geographically constrained, however, they are more resilient. A number of key central actors create the tacit norms of network coordination. This finding is similar to that of Domenech and Davies (2011) that revealed an important structural role of central actors in the case of the Kalundborg network.

1.5. Structure of coordination models of facilitation

In facilitated networks the facilitator starts by raising awareness among organisations that IS presents an opportunity. The regional development authority played a similar role in the loosely managed Styria network. The coordinator assumes the role of the central actor who facilitates exchange of information and alliance formation between firms. In these cases, IS exchanges resemble more common market transactions, though are aided by different levels of support and intervention by a third party facilitator. Paquin and Howard-Grenville (2011) observed that network processes change over time both in self-organised and facilitated networks. Drawing on the study of NISP in England, the authors identified **three key roles for facilitators**: ***1) 'conversation'; 2)'connection' and 3) 'co-creation'*** and a progress from more serendipitous types of processes at earlier stages of network development to more goal-directed processes as the network evolves.

The first phase has as its main focus to the building of awareness of the potential of IS and the recruitment of network members. Among the tools used by NISP in this phase were participation in industrial or sector-specific events, engagement with pre-existing networks and the organisation of "quick wins" events which provided the opportunity for companies to understand the potential value of IS for their own firm and engage in initial conversations with other companies.

'Connection' actions go a step further by connecting firms where there is a potential synergy to be explored and, in some cases, by providing more tailored support to strategic members through the different stages of the synergy realisation. Types of support include the funding of feasibility studies, technological or regulatory advice.

The 'co-creation' phase involves replicating and expanding successful synergies but also going beyond the state of the art project into more ambitious synergies and even a change towards more strategic projects, including infrastructure projects, promoting "regional resource capacity".

For the present study we have identified a typology of intermediaries that differentiate two extreme models in a continuum, varying from hands-off support to hands-on support:

- At one extreme of the spectrum there are **waste exchange web-based tools** or portals, where companies can input waste and by-products which may be of interests to other firms. These types of initiatives have had a very limited success and have generally only led to one-off, low value transactions. A review of online waste exchanged iniatives has been carried out as part of the EU-funded project SHAREBOX[3]. In many cases, developed websites are extremely simple and do not allow for more complex IT platforms that also enable learning or more in-depth interactions.
- On the other side of the spectrum we have **hands-on support structures**, which in many cases resemble or build on the NISP model (see section 2). In these cases, IS is supported by a team of experts or practitioners that engage with firms and other stakeholders for the purpose of the development of IS projects.

From a practical point of view, based on the mapping of IS ventures and facilitated networks in Europe, it is possible to identify a large **set of support activities undertaken by intermediaries.** This is not a comprehensive list, however, most intermediaries provide these services to a greater or lesser extent:

- Facilitation of the exchange of knowledge between actors belonging to different sectors of activity through a combination of methods including company waste audits, workshops, surveys and self-reporting initiatives
- Provision of technical support to overcome potential technological or regulatory barriers in the implementation of IS solutions
- Promotion of inter-firm collaboration and innovation by opening up the possibilities of reuse and recycling treatments that go beyond more standard solutions

[3] http://sharebox-project.eu/

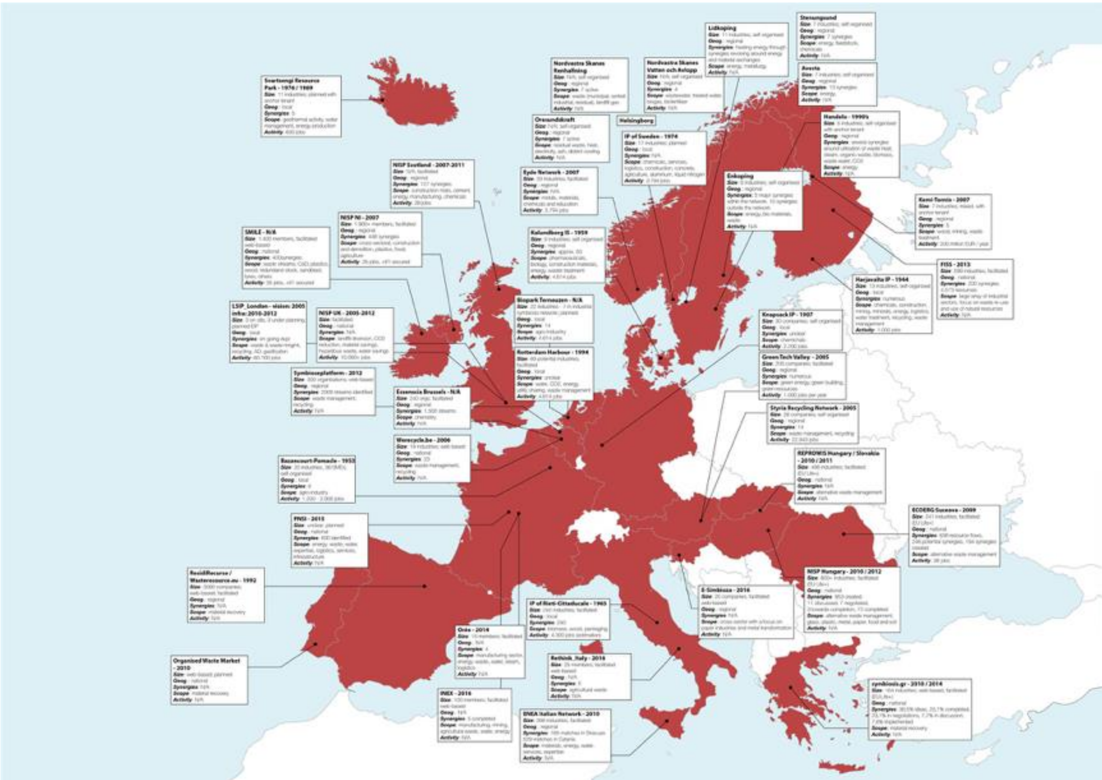
- Collection and assessment of resource data to inform opportunity identification.
- Feedback to government on potentially beneficial policy instruments that would be of assistance as well as reporting negative unintended consequences of regulation e.g. end-of-life/waste definitions.

Cases documented in this study, such as NISP, Catalisti, SMILE, etc., evidence that facilitation has the potential to promote and speed up the uptake of IS solutions and lead to greater environmental and economic private and social benefits. The following sections will provide an overview of the cases mapped and the structures used for facilitation.

2. MAPPING OF FACILITATORS OF IS COOPERATION IN EU

The mapping exercise suggests a number of differentiated patterns of IS networks in Europe. Figure 3 summarises key characteristics of established networks in Europe. More detailed information of each of these initiatives is provided in Appendix A.

Figure 3 Map of IS initiatives in EU



Source: authors

The mapping suggest that IS activity in Europe is very diverse in terms of its nature, emergence, development patterns and content of the transactions. Geographical scope and coordination mechanisms vary across initiatives. The sections below discuss key characteristics of IS in Europe. The mapping exercise has mainly relied on information from 'formalised' networks, those that report activity in the area of IS whether it is self-organised or facilitated. However, as acknowledged previously, it is likely that pockets of IS activity are happening to some extent in manufacturing and industrial clusters throughout Europe. Some of the specialised literature have 'unveiled' those pockets of unreported activity (see, Wolf et al. for the wood-paper industry (2007) or Domenech and Davies (2010) for steel and construction material cluster). However, **further research is needed to map IS activity in manufacturing clusters in Europe**.

Typologies of networks

There are examples of IS activity in the three typologies identified in this study: self-organised, facilitated and planned. Most of the examples of self-organised networks come from Northern countries and date back to the 1960s or earlier.

Among, self-organised networks, the case of Kalundborg is generally cited as a model for IS. IS activity was initially motivated by scarcity of freshwater for the manufacturing sector in the area and was initially driven by economic gains and cost-saving opportunities, generally linked to common development of infrastructure. Reuse of waste heat, steam and energy created additional opportunities for companies to explore further collaboration. It is also important to note that most companies in the initial Kalundborg network were and still are sustainability leaders in their sectors and there was an open dialogue between CEOs on business sustainability issues coordinated through an informal network, the 'green business club'.

Building on the experience of Kalundborg and a long history of district heating networks, a number of eco-industrial park initiatives and IS networks have been established in Scandinavia and neighbouring countries. They tend to have a strong focus on reutilisation of waste energy and heat through combined heat and power (CHP) systems, district heating networks and other opportunities to reutilise waste heat. Specific instruments have been put in place to favour these types of synergies. In Sweden, for example, the local investment plans (LIP) and the Climate Investment Programme (KLIM) have funded IS projects. The programmes' aims include promoting ecologically efficient systems, increasing the reuse of energy and material resources and improving circularity of nutrients. Local authorities are invited to develop local strategies in collaboration with local stakeholders in projects that generally have a 3-4 year span. LIP and KLIM generally provide 30% of funding for physical infrastructures (eukn, n.d.)[4] and have contributed to fund projects in Händelo and Lindberg, where waste heat of a cardboard mill was sent to a district heating network.

IS initiatives in key sectors such as forest industry and paper, chemicals, metals, mining and construction materials have also developed in several regions. Examples of IS activity between the wood and pulp and paper sectors in countries like Sweden and Norway are common. In an analysis of the forest industry in Sweden, Wolf and Petersson (2007) found that over one-third of the Swedish forest industry investigated in the study maintained IS transactions with neighbouring companies, involving energy, heat and material exchange. Monteras network is an example of this (Baas, 2011).

Based on the results of the mapping, **self-organised networks share some commonalities**: 1) they operate at the industrial estate level or local level; 2) they are generally linked to a clustering of manufacturing activities, with some primary sectors involved; 3) they have emerged as business-as-usual transactions in countries where social licence to operate is shaped by higher environmental awareness and more stringent environmental regulatory frameworks; It is also common to be driven by private actors but with with local government support and participation. Networks such as Kalundborg (Denmark), Harjavalta (Findland), Landskrona (Sweden), Kemi-Tornio (Findland) and Handelo (Sweden) follow this pattern.

Styria is another example of a long-standing self-organised network. Some coordination mechanisms have been developed over the years to promote further development of the network, however, most of the recycling/by-product activity is developed as bilateral market transactions (Posch, 2010). Styria in Austria sits in a large manufacturing cluster and the 'Green Tech Valley' and covers activities ranging from agriculture and food processing; wood, metal, paper, textile and plastic industries; and energy production. Self-organised IS activity has also been reported in the chemical clusters in Germany.

[4] See http://www.eukn.eu/e-library/project/bericht/eventDetail/local-investment-programmes-lip-and-climate-investment-programmes-klimp-1-1-can-be-3/

There is also evidence of IS activity that has developed in traditional manufacturing clusters as a consequence of the introduction of more stringent environmental regulation. Domenech and Davies (2011) report IS activity in a metal/cement cluster in Sagunto (Spain) driven by the introduction of stricter water, waste and air emissions regulation.

Facilitated networks and planned initiatives have also been developed across Europe. NISP UK is perhaps the most cited example of facilitated model for which there was monitoring of benefits achieved. NISP reported 45 million tonnes of waste diverted from landfill, 39 million tonnes in CO_2 savings, 58 million tonnes of virgin raw materials saved and cost-savings for industry of €1.21 billion over the period 2005-2013 (NISP, 2013). The facilitation model adopted by NISP has been replicated in other regions under different funding structures.

An example of a long-standing facilitated network in Europe is the IS Northern Ireland (previously NISP NI), funded by the business development agency Invest Northern Ireland. The programme, which is based on the NISP model, celebrated its tenth[h] anniversary in 2017. IS NI has reported cost savings of around £9 million, additional sales of £13.5 million and private investment of £1.88 million since 2007. It diverted 392,000 tonnes from landfill and contributed to CO_2 reduction of 261,510 tonnes. NISP Scotland (previously SISP) was initiated in 2007, also following the NISP model. The programme reported 312,295 tonnes of landfill diversion, 194,183 tonnes of CO_2e savings and costs savings to industry of around €4.65 million from 2007 until its termination in 2012.

Other facilitated initiatives have been launched in Europe in the last decade. They have different geographical scopes and are inspired by different facilitation models. Most of new facilitated activity has concentrated in eastern European countries (such as Poland, Hungary, Romania, Slovakia and recently Slovenia), with other relevant examples in northern and central Europe (Belgium, France, Denmark and Finland) and southern Europe (Italy, Spain).

Some of them have been active for a short period of time, linked to a project and specific funding stream (Life+, SPIRE, H2020, INTERREG and other European, regional and national funds), but have not managed to transition towards commercial models after funding has ended. Examples of this include programmes in Poland, Hungary, Romania and Finland. In the case of Hungary, Finland and Denmark potential follow-ups of the programmes are currently under discussion or awaiting budget approval.

Geographical distribution

The mapping reveals pockets of IS in different regions throughout Europe. As discussed above, northern and central Europe concentrate most of the examples of self-organised IS. However, the analysis also demsontrates that bilateral activity is common in manufacturing clusters across Europe, in many cases linked to more stringent regulation and incentives to divert waste from landfill. Attempts to replicate opportunities through facilitated networks have also extended to other parts of Europe, including eastern European countries and southern Europe. Performance of these initiatives varies considerably and will be discussed in more detail in the next section.

Geographical scope

When looking at the geographical scope of the networks, this also varies considerably across typologies of networks. Self-organised networks tend to have a local scope. Most core members generally involve neighbouring companies, although, in some cases, transactions may go beyond network boundaries, depending on: 1) the type of waste stream/by-product; 2) transport costs and 3) market value of secondary materials. The geographical scale of IS transactions will be discussed in more detail in the next section.

The geographical scale of IS self-organised networks tends to be restricted as it is dependent on: 1) information flows with regards to types of waste/by-products produced by other companies/facilities; 2) understanding of opportunities derived from IS transactions and 3) know-how and resources for implementing the IS synergies. These elements require a degree of collaboration among businesses to favour communication and willingness to find collective solutions. This is unlikely to emerge spontaneously between companies which are not co-located. Another key factor is transaction costs (including transport costs). This is very relevant in the case of IS, where marginal value tends to be very low or close to zero in some cases. In some cases, the figure of the 'waste manager' has contributed to the facilitation of synergies through finding ways to move waste up the waste hierarchy. This approach though has some problems, as waste management companies, as profit-seeking entities, tend to adopt more conventional recovery routes for waste and have generally their own optimised options for dealing with different waste streams. Companies also tend to focus on material resources, rather than the systemic view of IS that also includes energy, water and heat reuse opportunities.

Types of waste streams and distance

There is still little understanding of the role played by distance and transport cost in IS. Empirical research in this area is scarce. Jensen (2016) explores the role of geographical distance and industrial diversity as key variables influencing travel radius of synergies. His research is empirically based on the data from NISP England, based on the initial 650 facilitated synergies. The study found: 1) high correlation between area of industrial activity and presence of completed synergies; 2) distance travelled by resources was an average of 34 km; 3) synergies where the distance was greater than 34 km tend to occur in areas with lower geospatial diversity. The table below shows radius, mean diversity (different industries in one area) and completed synergies.

Table 1 Results of IS by type of industries and distance

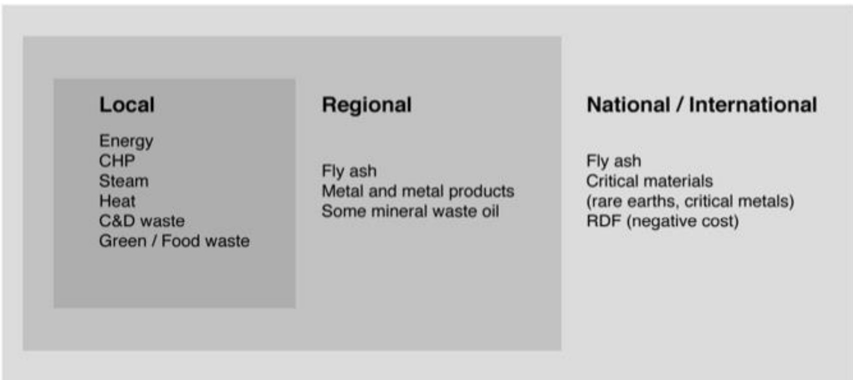
Interquartile mean and interquartile range of species richness and 1-*D* figures for sample plots relating to resources moving up to 65 km (at 5 km binned intervals).

Sample plot size (km)	Mean sR	sR range	Mean 1-D	1-*D* range	No. of synergies	No of synergy types
0–5	11	8	0.83	0.17	66	14(14)[b]
5.1–10	18	9	0.85	0.11	60	15(16)
10.1–15	22	3	0.88	0.07	43	12(18)
15.1–20	23	5	0.86	0.07	59	15(18)
20.1–25	24	3	0.86	0.10	39	11(18)
25.1–30	24	2	0.87	0.06	28	13(19)
30.1–35	24	2	0.83	0.09	46	13(19)
35.1–40	25	1	0.86	0.07	48	13(19)
40.1–45	25	0	0.84	0.10	26	10(19)
45.1–50	26	1	0.81	0.10	25	8(19)
50.1–55	26	1	0.81	0.08	18	10(19)
55.1–60	26	1	0.80	0.08	19	9(19)
60.1–65	26	0	0.85	0.02	12	7(19)
All synergies	24	4	0.84	0.08	650[a]	19

Source: Jensen (2016)

These findings are in line with the results from the mapping, which show **self-organised IS activity present in manufacturing clusters across Europe**. Similarly, Velenturf and Purnell (2017), based on a case study in the Humber region (UK), concludes that: 1) most companies can identify potential users of their resources and by-products from direct contacts and 2) that 73 % synergies tend to happen within a 75-mile (120 km) radius. This radius is considerably higher than the average found in Jensen (2016), but aligns with previous findings (Jensen et al., 2011) which indicate that 90 % of synergies took place in a 75 miles radius. This seems to suggest that resource types may substantially influence the radius of IS activity. Qualitative findings from the interviews, point to different geographical scope for different types of resources depending on: 1) type of waste stream and its physical and chemical characteristics; 2) value of the waste stream and 3) geographical distribution of resource recovery facilities. In general terms, bulky low value waste, such as construction and demolition (C&D) waste, tends to be restricted to local transactions, while low volume high value resources, such as cobalt, may have an international scope. Steam and waste heat exchanges are necessarily restricted to the local level, as they cannot be transported over long distances. Common metals such as steel and aluminium are generally traded in local/regional markets while more valuable and scarce metals and minerals can travel considerable distances, as shown in Figure 4.

Figure 4 Types of resources transacted by area



source: authors' own ellaboration

Size of networks

Size of networks also differs considerably across initiatives in Europe. Variation tends to happen depending on the geographical scope of the network. Regional/national networks naturally tend to have a higher number of members and local networks tend to be smaller in size. Networks included in the mapping exercise, for which there is data, had an average size of 473 members, but the median is 100 members, which indicates the variability of sizes and significance of small networks with local scope. However, looking at the number of synergies there does not seem to be a linear relation between the size and performance of the networks as some networks seem to be more successful in recruiting members and forging synergies between them.

Some of the research mentioned above (Jensen, 2016), however, found **high correlation between the size of the network, diversity of sector/activities and number of transactions.** However, the study was restricted to data from NISP regional programmes, and, therefore, more data is necessary to understand whether larger networks (with more members) are more successful in promoting synergies than more local, closely-knitted networks, such as Kalundborg.

One may argue that there may also be a trade-off between the size of the network and the ambition and complexity of the project they embark with. Domenech and Davies (2011), suggest that closely-knitted networks can lead to embeddedness favouring initiation and development of IS synergies. Facilitation models have tried to reproduce embeddedness mechanisms in larger networks.

Key sectors

In terms of key sectors, there is considerable variation. Primary sectors such as pulp and paper, power production, forestry, metal, mining and construction materials tend to play an important role in self-organised IS networks, acting in many cases as anchor tenants of the network (see, for example, Kalundborg, Monteras and the chemical clusters in Germany). However, a characteristic of IS networks is the diversity of sectors involved and the opportunities created across different activities and supply chains. This diversity, which was also found to be a crucial factor promoting IS according to Jensen (2016), has been stressed in primary data collected through interviews for the networks investigated. Appendix A includes an indication of sectors represented in the networks.

Economic, environmental and social benefits

The study also identifies important data gaps in the way IS networks are monitored and evaluated. Very few studies have provided quantification of IS benefits in Europe (Karlsoon and Wolf, 2008; Van Berkel, 2010; Sokka et al., 2011). Quantification methods have used a combination of tools from the industrial ecology field and have generally been applied to a regional or local network. Wolf and Karlsson (2008) use an optimisation method to assess reduction of GHG associated to IS compared to standalone activity in the forest industry, covering the activity of a pulp mill, paper mill and biofuel production. Van Berkel (2010) and Jacobsen (2006) use direct estimation of benefits associated with IS activity for Kalundborg. Following Van Berkel (2010), the quantification may refer to three different processes that may occur through the synergies: conversion, substitution and avoidance. Conversion refers to processes related to transforming a previously-wasted material, water or energy from its source to its treatment and processing to be transformed into a suitable feedstock. The substitution process refers to substitution of orginal (virgin) stock by a secondary source and adjustments of processes/quantitites if required to compensate for the lower grade of the resource and, finally, avoidance processes that refer to the elimination or reduction of disposal costs.

In most of the mapped cases, however, networks do not have any monitoring framework in place and lack harmonised mechanisms of data collection and quantification of benefits. Opportunities exploited through the network are largely unquantified, although generally, some general understanding of areas of benefits are perceived by members and facilitators. This happens across all categories of potential benefits (environmental, social and economic). This has been confirmed by the survey and interview findings, suggesting substantial economic, environmental and social benefits associated with IS activity, which go largely unreported for a number of different reasons, such as resistance of companies to provide data, lack of coordination mechanisms that collect and maintain the data and lack of technical capability and time to analyse the data. Benefits include costs savings linked to reduced waste and environmental management costs but also savings in sourcing of primary materials. This is consistent with the information collected for the few data points where this information exists, and include both spontaneous and facilitated networks. Some examples of benefits reported by self-organised activity are summarised in Table 2. A comparison of performance for facilitated programmes is included in next section.

Table 2 Benefits reported by self-organised networks

Network	Benefits reported
Kalundborg	2 million cubic meter/year ground water saved; 1 million cubic meter/year surface water saved; 200,000t natural gipsum saved 200,000t fly ash used as secondary material 2,800 tonnes of sulphur saved
Styria Network	approx. 1 million tonnes of by-products gathered, 780,000 tonnes recycled, 200,000 tons landfilled or incinerated; 25,000 tonnese handed to professional waste management Further, 330,000 tonnes were further identified as potential secondary materials 70 % recycling rate 42 % CO_2 emissions saved 25 % of final energy consumption from renewable sources
Harjavalta	Long-term waste management waste from process (iron cake, etc): 19,000 t/y hazardous waste: 121t/y Utilisation / special processes energy waste: 351 t/y metals: 181 t/y lead: 83 t/y hazardous waste: 124 t/y recycled paper: 15t/y household waste: 16 t/y "Utilisation level": 81.8 %
Handelo	Using an LCA based approach, Martin (2014) identifies benefits associated with integration of bioethanol and biogas in Handelo and associated exchange of by-products and waste materials. The analysis quantifies a significant reduction of GHG emissions in the existing scenario (pre-2009) compared to stand alone production and 3 scenarios point to further opportunities derived from reutilisation of by-products and waste streams for biofuel production. Savings can amount up to 35 % reduction compared to stand alone production. The analysis also shows potential for reduction of acidification, although this depends on the system of reference adopted and a potential negative trade-off with the eutrophication impact category.

Source: compiled by author based on Jacobsen (2006); Martin et al. (2014); Posch (2010) and Nordregio (2015).

3. ASSESSMENT FRAMEWORK FOR INDUSTRIAL SYMBIOSIS

3.1. Existing assessment frameworks for industrial symbiosis

The mapping exercise has demonstrated occurrence of self organised and facilitated IS activity in Europe and perception of economic, environmental and social benefits in its various typologies. The mapping though has also revealed substantial data gaps in the appraisal of the networks, something confirmed by the survey and interview findings.

Although assessment frameworks have been developed to quantify benefits along the three pillars (see, for example, Van Berkel, 2010 or Martin et al., 2014), findings highlight the absence of harmonised frameworks for assessing performance of IS activities and continuous monitoring of IS activity, be they self-organised, facilitated or planned. Existing assessment frameworks range from simplistic (comparing before and after for resource use, for example) to extremely thorough (e.g. through LCA). In most cases, though, quantification of benefits by self-organised activity provides a snapshoot at one point in time, but there is lack of consistent monitoring over time.

Much of the industrial symbiosis activity, however, has not been formally assessed and there is a lack of systematic data gathering procedures. Although evidence suggests that companies engage in industrial symbiosis for competitive/pragmatic reasons, the internal assessment as part of business decision-making is, in general, not shared externally. An overview of assessment frameworks for networks also suggests that selection of assessment metrics responds to different policy priorities.

Most systemically applied assessment frameworks have been developed by publicly invested/funded networks such as NISP and IS Northern Ireland, as a result of requirements from the funding authority. The definition of assessment frameworks and selection of metrics may indeed play a critical role influencing: 1) the type of activities developed by the network and range of services offered by the coordinator; 2) the nature of the synergies promoted. In the case of facilitated activity, generally, two main approaches have been devised for the evaluation of networks: 1) goal directed and 2) service/activity oriented. **Goal directed** approaches tend to focus on reporting the impact of the IS activity and environmental, social and economic benefits associated with IS transactions facilitated through the network (e.g. landfill diversion, CO_2 savings, cost savings etc.), while **service oriented** approaches report on the services offered by the network (e.g. number of workshops conducted, companies engaged, hours given in assistance/advice etc.). It is also possible to combine both approaches to provide a more comprehensive picture of IS facilitation performance.

Although synergies resulting from self-organised activity are generally no different from those resulting from facilitated ones (the difference is on how the opportunity is identified and advanced), the expectation on information sharing may be very different. By the very nature of self-organised networks, participants are not subject to reporting or assessment; thus, initial evaluations on these uncovered networks have necessarily been outside-in estimates and some of the first e.g. Kalundborg (Ehrenfeld and Gertler 1997; Jacobsen 2006) focused on estimating environmental and economic savings: water, fuel, waste avoided and input costs. In the case of Puerto Rico, where synergies resulted from cogeneration required by planning constraints, Chertow and Lombardi (2005) estimated environmental and economic benefits using external estimates for the resources involved, as the participating companies were not forthcoming with detailed information.

Recent industrial symbiosis facilitated through the H2020 project EPOS[5] reported quantified economic benefits as a feasibility assessment (initial investment, annual economic benefits and calculated payback time) and concluded that environmental benefits are 'ambiguous'.

Survey results targeted at facilitation programmes in Europe suggest that quantitative information on network performance is only available for a reduced number of networks, generally, for those publicly-funded programmes that have run for a number of years (e.g. Northern Ireland IS, NISP or SMILE). These initiatives have relatively good metrics, which are part of their reporting requirements. However, in many cases, facilitators do not collect data on the synergies they helped to facilitate and/or do not report benefits in a systematic way. Programmes funded by short-term funds or project funding streams (e.g. H2020, Life+, etc.) tend to be too short to go beyond the feasibility stage and benefits reported are limited to a small number of IS projects. In the interviews, facilitators also have stressed the difficulties in gathering data on the benefits derived from the IS transaction once it has been facilitated, as some companies may find it difficult to quantify and some may be reluctant to share. One of the interviewed facilitators, stressed that data collection can be hard:

"*there are the companies who don't always want to give the information or they don't know, or also it can be that the coordinators don't have time to really estimate and calculate all of the impacts*"

The lack of harmonised methods of assessment, data gathering and monitoring resulting in uncertainties and inaccuracies provide a difficult ground for comparatively assessing performance across different network typologies. Adding to this, the great variation in geographical scope, size and, in the case of facilitated programmes, available funding makes comparison across initiatives unreliable. Table 3 below presents a comparison of metrics for the networks/projects where monitoring metrics have been adopted. The table includes a combination of different typologies of networks in and outside Europe. NISP and KICOX both started as large-scale facilitated activities, with the difference that KICOX is centered around industrial parks (eco-industrial park approach), while INES started as a facilitated initiative with a local geographical scope and Kalundborg stands as a self-organised network. The table indicates that in most cases reporting of benefits covers both environmental and economic dimensions. Environmental benefits tend to capture savings in materials and emissions while economic benefits include cost savings benefits, additional revenues for the industry and in some cases investment and payback times.

Table 3 Assessment metrics used by IS networks

Metric	NISP UK(a)	KICOX Korea (b)	Kalundborg ©	INES, Netherlands (d)	Devens, USA (e)
Landfill diversion	√	√ (solid waste)			√
Virgin raw material savings	√		√	√	
Water saving	√	√	√	√	
CO2 reductions	√	√	√	√	
Emissions (SO_x etc.)		√			
Energy		√			
Hazardous waste avoidance	√				
Additional revenues	√	√	√	√ (not reported)	
Cost savings for industry	√	√	√	√ (not reported)	√
Net investment		√	√	√	
Payback time			√	√	

[5] see https://www.spire2030.eu/epos

Metric	NISP UK(a)	KICOX Korea (b)	Kalundborg ©	INES, Netherlands (d)	Devens, USA (e)
Jobs created/safeguarded	√	√			
No. businesses engaged	√				√

Sources:

(a) NISP Pathway to a Low Carbon Economy 2009

(b) Compiled from: Eco-Industrial Park is the future. www.eip.or.kr 2010. KICOX, Ministry of Knowledge Economy; Eco-Industrial Park Construction Plan 2010.09. Ministry of Knowledge Economy.

(c) Compiled from Jacobsen and Anderberg, 2005, Understanding the Evolution of Industrial Symbiotic Networks – the case of Kalundborg; and http://www.symbiosis.dk/en/. No uniform reporting.

(d) Compiled from BSE 2011 Baas, Uncovering IS in Rotterdam; JCP 2004 Boons & Baas, An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems. No uniform reporting.

(e) Veleva et al. 2014. Understanding and addressing business needs and sustainability challenges: lessons from Devens eco-industrial Park. Journal of Cleaner Production 87: 375-384.

KICOX, coordinator for the Eco-Industrial Parks supported by the Ministry of Knowledge Economy in the Republic of Korea, has measured outputs against government investment in terms of: cost reduction/new sales and reductions in solid waste, waste water and greenhouse gases together with new investment. In the case of NISP UK, reporting and evaluation responded to both goal-directed (e.g. landfill diversion achieved) and service-oriented (number of companies engaged) approaches. In the case of IS Northern Ireland, reporting was initially goal-directed but has over the year shifted towards more service-oriented approaches (reflective of their financing by the European Regional Development Fund (ERDF) which is orientated to documenting activities, e.g. business assists more than impact). In the rest of the networks analysed, data gathering has been less systematic and reporting of benefits less consistent. Some of the short-lived initiatives funded by EU projects reported some benefits in their final reports but they have not been since monitored or updated, as in many cases the projects have been discontinued through lack of continued investment. The Danish national programme also reported significant problems in accurately capturing the results from IS facilitation. In this case, reported benefits only included the number of synergies identified at different stages (from idea to implementation) for water, energy and materials. However, impacts of the synergies were not calculated. The final report of the programme in 2015 also mentions lack of clarity with regards to the status of the synergy and inability to gather relevant data from businesses for which matches were identified.

NISP UK provides a reference for quantified and third-party audited outcomes (through an assessor appointed by Defra, the governmental contracting body). NISP benefited from investment from the landfill tax escalator, with additional funding in some regions supported by regional development agencies (now abolished in the UK). In those regions reporting on metrics included aspects such as the creation and safeguarding of jobs, new start-ups and private investment in reprocessing. In later phases, when NISP regional 'spin offs' were supported through a different funding scheme (ERDF), it was also required to report on the service-orientated metrics as mentioned earlier. The targets provided a clear framework for assessment of the network and evaluation of its performance, as well as determining the activities and synergies pursued by the coordinators. It is crucial to understand these initial drivers/investor requirements on the direction/impact of industrial symbiosis activity of all forms. NISP metrics have also been adopted by other facilitated programmes across regions, as will be described below.

Single Metric Impact Framework: TEVA

A single metric approach for measuring performance of facilitated networks has also been applied to the evaluation of performance of IS. The approach is based on natural capital valuation methods and provides a combined single metric which considers environmental, social and economic benefits.

The metric was adopted to measure the impact of the first 5 years of operation of the NISP UK programme in a study by Scott Wilson Business Consultancy and Manchester Economics (REF). In assessing the total impact of the public intervention, they recognised that combining strict economic values with wider benefits (e.g. monetary values for environmental gains) provides a better measure of overall economic benefit. The measure is called Total Economic Value Added (TEVA) and in this case it was calculated combining the following aspects:

- The additional sales and cost savings by the businesses (commercial added value [CVA]) which gives rise to additional gross value added (GVA)
- Community regeneration benefits from safeguarding and creating new employment (social value added [SVA]) and the benefits from reduced emissions (environmental value added [EVA])
- Finally, Exchequer fiscal flows: increased GVA leads to an increase in taxes paid through corporate taxes, income taxes and VAT.

At the time of the study, TEVA was calculated for NISP at between £1470 m and £2450 m which represented an investment multiplier on the public investment of between 53.2% and 88.6%, leading to the conclusion that 'the triple line benefits achieved to date provide a compelling case for increased investment in the future' (Ref NISP Pathway 2009 p. 8).

The value of this approach for policy-makers is that there are measures such as TEVA that can be used when comparing programmes of a different nature. In deciding whether to invest in an IS programme, public bodies are able to compare the opportunity cost of achieving their policy goals and determine value for money and return on investment. However, this requires accurate data and harmonised assumptions for calculation of TEVA.

LCA Approaches to measuring IS activity

There have been some attempts at using LCA approaches to measure the impact of IS. Daddi et al. (2017) measured the impacts of IS using an LCA approach comparing two scenarios in a tannery cluster in Italy. The cluster has expanded over six municipalities and produces 66 % of the total EU production of tanned leather. The study compared two scenarios: one with industrial symbiosis and one with a lower level of adoption of IS. The first scenario reflects the actual performance of the cluster while the second one is a theoretical scenario based on data from other similar tanning clusters in Italy. The results show that the IS scenario reduced environmental impacts in all impact categories, climate change and freshwater eutrophication being the ones more positively impacted by IS (as seen in Table 4 below).

Table 4 LCA approach to measuring IS

Impact category	Unit	Unit: 1 m^2 finished leather		*Difference*
		Scenario 1	Scenario 2	
Climate change	kg CO2 eq	15.34	19.64	−21,87%
Ozone depletion	kg CFC-11 eq	9.32E-06	9.46E-06	−1,48%
Human toxicity, non-cancer effects	CTUh	9.40E-06	9.67E-06	−1,48%
Human toxicity, cancer effects	CTUh	6.147E-06	6.61E-06	−7,00%
Particulate matter	kg PM2.5 eq	0.0121	0.0143	−15,38%
Ionizing radiation HH	kBq U235 eq	0.846	0.941	−10,10%
Ionizing radiation E (interim)	CTUe	6.75E-06	7.52E-06	−10,24%
Photochemical ozone formation	kg NMVOC eq	0.06092	0.07072	−13,86%
Acidification	molc H+ eq	0.19002	0.21517	−11,69%
Terrestrial eutrophication	molc N eq	0.38306	0.47014	−18,52%
Freshwater eutrophication	kg P eq	0.00160	0.00182	−12,09%
Marine eutrophication	kg N eq	0.04686	0.05014	−6,54%
Freshwater ecotoxicity	CTUe	85.11	92.17	−7,66%
Land use	kg C deficit	132.57	138.97	−4,61%
Water resource depletion	m3 water eq	0.80887	0.82329	−1,75%
Mineral, fossil & ren resource depletion	kg Sb eq	0.01808	0.01837	−1,58%

Source: Daddi et al. (2017)

In the case of the tannery cluster mapped in this study, there was no coordinator or facilitator actors but rather IS opportunities developed over the course of 30 years in consonance with pressures from the supply chain (mainly linked to luxury goods and international brands) to improve environmental performance and pressures from local authorities and residents to control negative externalities linked to odours and pollution. The environmental reporting procedures in the firms eased the process of data collection, as companies where keeping track of key aspects (as part of the requirements imposed by the supply chain). Most of the IS transactions involved the sharing of infrastructures that created by-products from the tanneries waste waters and recovery of some of the heavy metals. In many cases, the infrastructures were the result of PPPs that involved SMEs and local government.

The H2020 project SHAREBOX[6] is proposing reporting impacts assessed by LCA: while various LCA impact categories were considered relevant (greenhouse gases, ozone depletion, human toxicity, particulate matter, ionising radiation, photochemical ozone formation, acidification, eutrophication, eco-toxicity, land use and resource depletion), greenhouse gas emissions and an energy related impact indicator like primary energy demand are seen as the most likely to be chosen at the time this report is written (January 2018). However, it is not entirely clear at this stage how calculation from raw data to complex LCA calculations will be made by the system.

LCA provides a good framework for assessing environmental impacts of IS, although it does not consider other important pillars of IS, which refer to economic and social benefits. This could be done by extending the LCA to also cover economic and social impacts. However, the main limitation for these types of approach is that they require a level of detail of data that is generally difficult and costly to gather.

3.2. Key issues to consider in the design of evaluation frameworks

How to measure impact: Targets and constraints drive activity

Where desired outputs are defined in goal-directed approaches, then practitioner time and activity will first be directed to those sectors/materials that are most likely to deliver the priority outputs – be they environmental, economic or social. To illustrate, if IS success is determined by achieving substantial landfill diversion (goal-directed), then target sectors are likely to include construction, cement, and foundries for the large volumes of materials mobilised. This was the case in NISP UK 2005-2009 where initially the programme was directed to deliver tonnage diversion from landfill. Later in the programme Defra priorities changed to specific

[6] http://sharebox-project.eu/

materials such as plastics. Alternatively, where the key metric is innovation, the coordination focuses on attracting entrepreneurs and innovators, SMEs and those SME-enabling bodies with relevant networks, as in Finland since 2010.

Evaluation frameworks of existing/past facilitated programmes or being suggested for future programmes need to account also for any constraints placed upon the IS activity. Constraints that limit the scope of programmes by sector, material type or organisational type may result in trade-offs. For example, in the later phase of NISP UK, in 2009-2013, Defra limited the activity to certain materials and sectors, even though this created some incongruences: for example, plastics were targeted but the construction sector was off limits – so the plastics mobilised within the construction sector were not within the scope. There is also a temporal aspect that can direct practitioner effort. If targets are set on a yearly basis this may create a bias towards IS transactions that can be completed in the short term. Consider the case of landfill diversion or carbon reduction annual targets set by the initial NISP programme targets versus pursuing eco-innovative synergies that may engage demand-led research and innovation, but take several years to generate results – short-term targets may preclude longer-term investment in innovation and concomitant job and wealth creation. This is an aspect that has also been raised in the case of Denmark, Finland, Hungary and Romania, where short-term funding was seen as a barrier to facilitating IS transactions as many of the proposed IS opportunities took longer than a year to realise.

Temporal, attribution, rebound and leakage impacts on assessment

Further aspects of measurement relevant to any comprehensive assessment framework for industrial symbiosis include:

TEMPORAL - an industrial symbiosis transaction or 'synergy' may be a 'one off' or continue at the same level or increase or decrease over time. In most of the assessment frameworks, the network's impact is considered only for the year the transaction is first established independently whether this may be sustained over time or not. Partly this is explained by the difficulty in keeping track of transactions over time and to avoid double counting. This temporal aspect was addressed by Defra in the UK and reflected in the Scott Wilson and Manchester Economics report by adopting scenarios ranging from a discounted model declining to zero benefits over a five-year period to a scenario that maintained benefits at the current level for five years before being assumed to be zero. This is a reasonable approach in that after a period of time what can clearly be identified as IS today could be standing operating practice for industry in the future. In most assessment frameworks, synergies are counted as one-off. In the case of self-organised networks, such as Kalundborg, yearly benefits are calculated including pre-established active synergies, resulting in incremental symbiosis.

ATTRIBUTION – One area that may require attention is how benefits are attributed between businesses and organisations and the coordination body. In the case of NISP, where impact was audited through an independent verification process, companies were asked to reply (on a scale) to what extent had the facilitated programme contributed towards the action they had taken. Where the companies responded they were already on a course of action, it was established whether the programme had the effect of bringing that action forward in time and if so by how long.

REBOUND/REALLOCATION – An impact of IS is a disruption on the status quo so that whereas companies participating in a synergy may see an economic benefit, elsewhere in the economy there may be a dis-benefit e.g. where a material was going to landfill through a conventional waste handler that material is no longer available for that disposal route resulting in a loss of income for the waste handler. Therefore, assessment frameworks need to consider the synergy's trade-off effects. This reallocation effect was incorporated into the model designed to quantify NISP impact.

LEAKAGE – In an open system such as facilitated IS it is impossible to capture/monitor all the benefits that occur as actors are free to operate outside the boundaries of the programme (especially having been introduced to solution providers); this activity will never be included in results, but is known to happen. Similarly, only direct benefits are typically recorded. The following are generally excluded (not captured): spillover effects associated with replication of best practice and economic benefits/jobs created elsewhere in the economy by companies investing in plant and equipment to make the synergies happen.

Using ICT platforms for quality assurance/reporting

Independent verification of industrial symbiosis metrics/outputs achievements from facilitated models are essential for confidence levels, but expensive over a protracted period of time. To address this specific challenge, a number of programmes have incorporated within their standard operating procedures web-based platforms that track synergies through different stages. An example is the ICT platform Synergie developed for NISP and managed by practitioners, which proposes a five-stage gateway process to manage the IS synergy initiated (from idea to completion). When the system was adapted to other contexts (France, Finland, Belgium, Brasil, China, etc.), the impacts were adjusted to suit the specific programme – but the tracking and data management methodology remained the same.

INEX (France) has also developed a platform that incorporates a GIS system to track synergies and identify potential systems.[7] Other web-based platforms have been developed as a result of other EU funded initiatives, including FISSAC (web-based platform for the construction sector), ERMAT (Sectorial market platform) or SHAREBOX (developing a 2.0 version of Synergie).[8] In theory these systems could generate 'systems' of performance reporting which would increase the quality and consistency of data and reduce downstream costs of verification. However, the proliferation of different platforms that do not speak to each other, nor as]re standardised, contributes to more rather than less complexity for IS assessment.

3.3. Conclusions on assessment frameworks for IS

A mix of environmental, economic and social indicators have been applied in IS activity, although only the large national activities in the UK and Korea have systematised their consistent application. There is a lack of harmonised frameworks and data reporting structures that ensure data accuracy and comparability. Both managed and unplanned activity have generally been assessed using similar metrics (BSE 2011 Baas), which capture the triple bottom line benefits of industrial symbiosis. However, the lack of a central coordinator in self-organised activity have meant in many instances that IS activity is not reported. Approaches from natural capital valuation were used in the case of UK NISP to convert impacts to macroeconomic analysis. Such an analysis requires good accurate and consistent data and is based on a number of assumptions. Such calculations are generally outside of the scope of most smaller programmes, which are constrained by time and funding arrangements. LCA approaches have also been used to evaluate IS contribution to impact reduction. Again, data availability and time are generally key limitations to the adoption of such approaches. Sensitivities to be considered include funding/investment requirements and priorities, as what is measured determines activity e.g. for practitioner time. Finally, ICT plays a role in tracking and reporting auditable measurements. However, the proliferation of different web-

[7] https://www.inex-circular.com/

[8] See project websites at https://fissacproject.eu/en/ (FISSAC project), http://sharebox-project.eu/ (SHAREBOX) and https://eitrawmaterials.eu/project/ermat/ (ERMAT project)

based platforms and lack of integration contributes to increased problems of data standardisation and comparability.

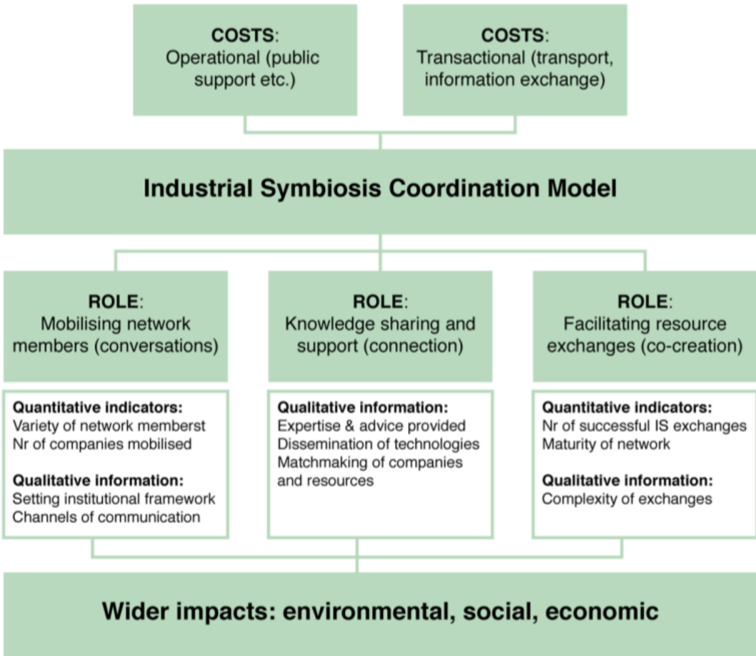
In conclusion, evidence suggests that suitable frameworks for assessment exist and have been rolled out nationally as for example for NISP UK, which was externally verified. However, most IS activities have not been required to apply a rigorous reporting structure, thus comparable data is currently absent. For a better comparison and quantification of IS potential and network performance, adoption of harmonised assessment frameworks and consistent data collection systems would be needed.

This current situation gives rise to the questions regarding the evaluation of: 1) value added of facilitation; 2) potential of IS; those elements are indeed critical to understand the role played by facilitation in promotion of IS and, more generally, resource efficiency and the transition towards a circular economy. The sections that follow provide an assessment of facilitation in Europe based on the results from the survey and interviews.

4. ASSESSMENT OF IS FACILITATION IN EUROPE

Based on the analysis of assessment frameworks for IS and the concept of IS adopted in this report, an assessment framework for IS facilitation has been developed (as shown in Figure 5). The assessment framework considers three main pillars: 1) costs associated with coordination, including operational costs and transactional costs; 2) roles and functions developed by IS facilitation/coordination along the continuum of conversation, connection and co-creation activities and 3) impact of the facilitation, considering environmental, social and economic benefits derived from facilitated IS activity.

Figure 5 Assessment framework for IS coordination mechanisms



Source: authors

The following chapter provides an overview of the results of facilitated networks in Europe based on this analysis framework. However, it is important to note that the results presented in this chapter are based on the survey and interviews with representatives of the IS initiatives, without any possibility of independent verification. Therefore, the results presented below should be treated with caution, as they provide an indicative basis for assessing performance of existing IS facilitated initiatives.

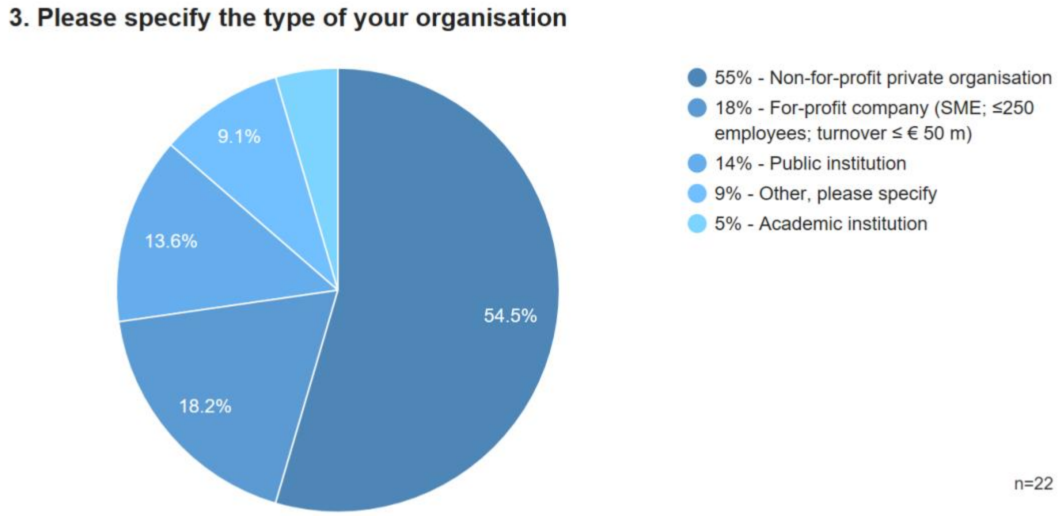
4.1. Costs and funding structure of facilitated industrial symbiosis initiatives

In many cases, specific costs are associated with industrial symbiosis activity. Those costs, generally called transaction costs, may include costs related to the exchange of information, learning costs associated with the adaptation to the new situation and transport costs. Generally, transport costs are very relevant for resources (secondary materials) with a low market value by volume, which may compromise the economic viability of an IS opportunity. Since in many cases the transport costs may be incurred by the purchaser of the resources, high transport costs can reduce the advantage of an IS opportunity. Also, for some resources, low market value of primary raw materials may create disadvantageous conditions for using secondary raw materials or by-products. An exception to this is when the by-product also adds desirable characteristics to the resource as for example in the case of steel slag used for cement production.

In addition to the transaction costs common to self-organised and facilitated activity, facilitated IS also has associated operational costs to cover facilitation activity. Operational costs include the labour costs of experts and practitioners, costs associated with organising events and costs associated with match-making, negotiation and advising.

Results from the survey and interviews suggest that intermediation activity is mainly being undertaken in Europe by small not-for-profit organisations (Figure 6), generally operating in the area of sustainability or regional development. In many cases, network facilitation is the result of partnerships between different stakeholder groups including the third sector but also private and public sectors.

Figure 6 Types of organisations facilitating IS



4. What types of organisations are part of your IS Network's governance structure?

Response	Total	%
A private company	13	59%
Government body	11	50%
University	8	36%
An advisory group of experts	6	27%
Other, please specify	5	23%
Cluster	5	23%
An NGO	4	18%
Do not know	0	0%

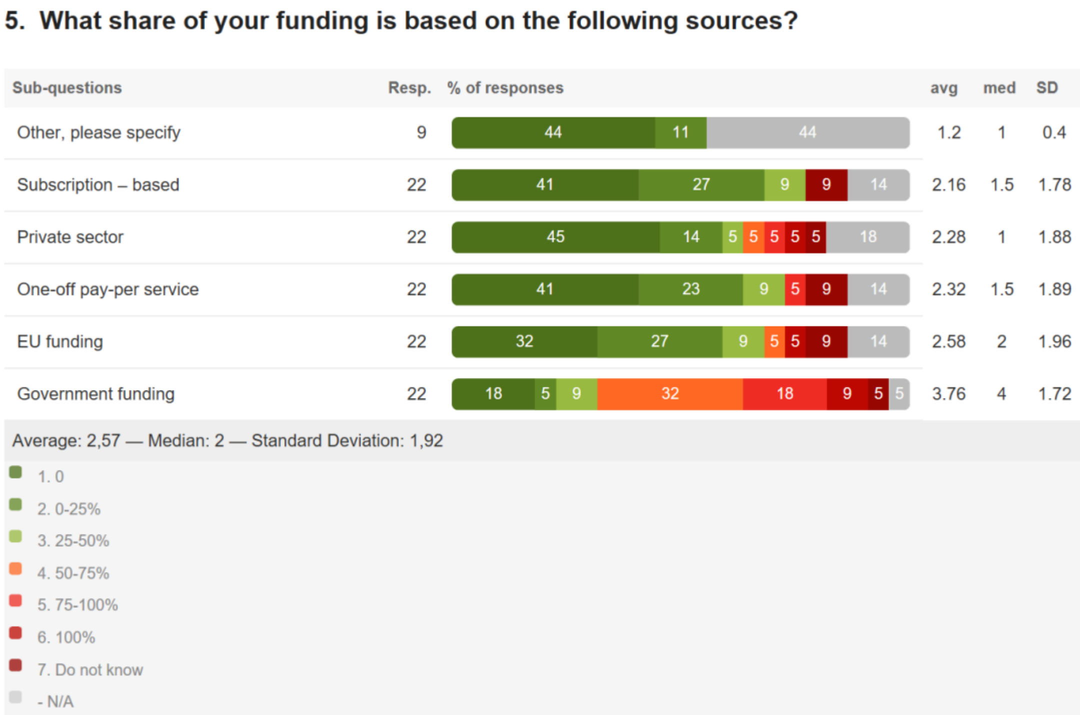
Total respondents: 22
Skipped question: 0

Source: authors based on survey with IS facilitators

The survey results also indicate that funding to support IS activity comes primarily from the public sector, although this may be complemented by other contributions from members in the form of subscription frees and one-off payments for services.

None of the surveyed facilitated programmes relied solely on private funding. Some of the programmes interviewed, such as the recent INEX, believe fully commercial IS activity is possible. However, their business model currently revolves around selling the match-making (web) app to potential facilitators rather than facilitating IS on the ground. Interviewees representing facilitated programmes across Europe were sceptical about fully commercial IS facilitation on the basis of a number of barriers to clearly allocating benefits and lack of financial incentives. This will be discussed in section 6 in more detail.

Figure 7 Funding sources for IS facilitators



Source: survey with IS facilitators; multiple-choice question

Another attempt at commercial facilitation is NISP UK, which started as a fully governmentally-invested activity from 2005 to 2013. The attempt to commercialise failed to achieve the revenues needed to maintain a national programme engaging with many thousands of companies. The programme continues at a much smaller scale in partnership with local and regional actors, typically supported by European Structural and Investment Funds (ESIF).

Operational costs of the facilitation have been restricted to the funding available. Invest Northern Ireland has maintained a facilitated IS programme, operational since 2007. The SMILEe programme in Ireland has also been publicly-funded since 2011, first locally and since 2014, operating nationally. Facilitated symbiosis linked to specific project streams such as Life +, H2020 or ECOREG has been more restricted in terms of temporal scope and funding (see Table 5).

Table 5 Operational costs of selected facilitated networks

Programme	Total Budget (€mill.)	Years of operation	Budget /Year/€mill.
NISP Scotland	1.28	5	0.256
NISP Hungary	0.79	2	0.39
NISP UK	44.39	7	6.34

Romania ECOREG	0.88	2	0.44
Danish Industrial Symbiosis Programe	4.6 (16m DKK)	3	1.53
SMILE Ireland	Cca. 0.9	6	Cca 0.15
Finnish Industrial Symbiosis System (FISS) preparation (2013-2016 pilot)	0.645	3	0.2 (approx.)
Finnish Industrial Symbiosis System full programme implementation at regional level (2013-2020)	4.6	8	0.575

Source: authors based on programme documents received from facilitators or interviews with the programme facilitators.

More important than the costs as such is the comparison of costs against benefits. This will be covered in Section 4.3.

4.2. Assessment of functions of facilitation

According to the framework above, IS facilitators' activity can be organised across a continuum of services offered:

- Conversation (mobilising network members)
- Connection (knowledge sharing)
- Co-creation (facilitating transactions and implementation of synergies)

Services across facilitators in Europe may vary but they generally include: 1) match-making services; 2) information and awareness raising; 3) knowledge transfer and 4) provision of advice and support through different IS stages.

Figure 8 below shows that these are also the services that are considered more effective in promoting IS, stressing the relevance of awareness raising, match-making and knowledge transfer. The services provided contribute to overcoming some of the barriers identified in scaling up IS opportunities, as shown in Figure 8.

For example, match-making services aim to overcome informational barriers. Knowledge transfer also contributes to overcoming informational barriers but also help to shape adequate regulatory frameworks or find solutions for current regulatory hurdles. Cultural and organisational barriers can also be achieved through information and awareness raising activities and knowledge transfer.

Functions of IS facilitation also vary according to the evolution of the network and the synergy. At earlier stages of the network, conversation activities to expand network members and sector may prevail. Connection activities including scan of resources and potential opportunities will then develop and some of them may evolve towards co-creation of synergies at later stages. The table below also shows how facilitation functions vary in the process of synergy implementation from the inception stage to realisation.

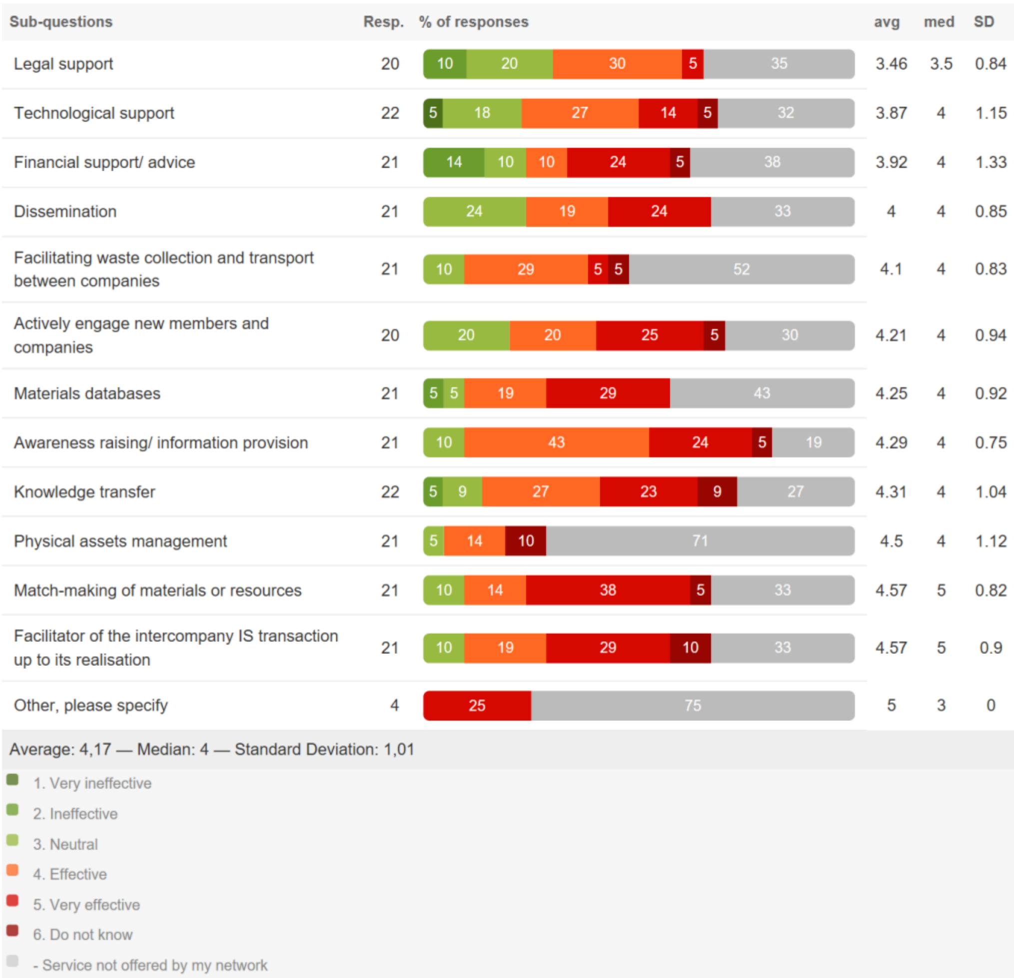
Table 6 Role of facilitation by stages of implementing IS

Stage	Type of activity	Role of facilitation
Identification of symbiosis potential – Idea stage	Conversation	Facilitate potential opportunities based on resource flows
Qualified symbiosis – feasibility stage	Connection	Provide advice on legal/regulatory/market/technical issues In some cases undertake feasibility studies
Established symbiosis –	Co-creation	Facilitate negotiate/provide advice to overcome potential regulatory barriers;

Implementation stage		provide funding for implementing identified synergies
Completed synergy	Connection/co-creation	Monitoring; reporting; dissemination of best practices; learning implementation for other potential cases

Source: authors

Figure 8 Effectiveness of the services offered by IS facilitators to companies



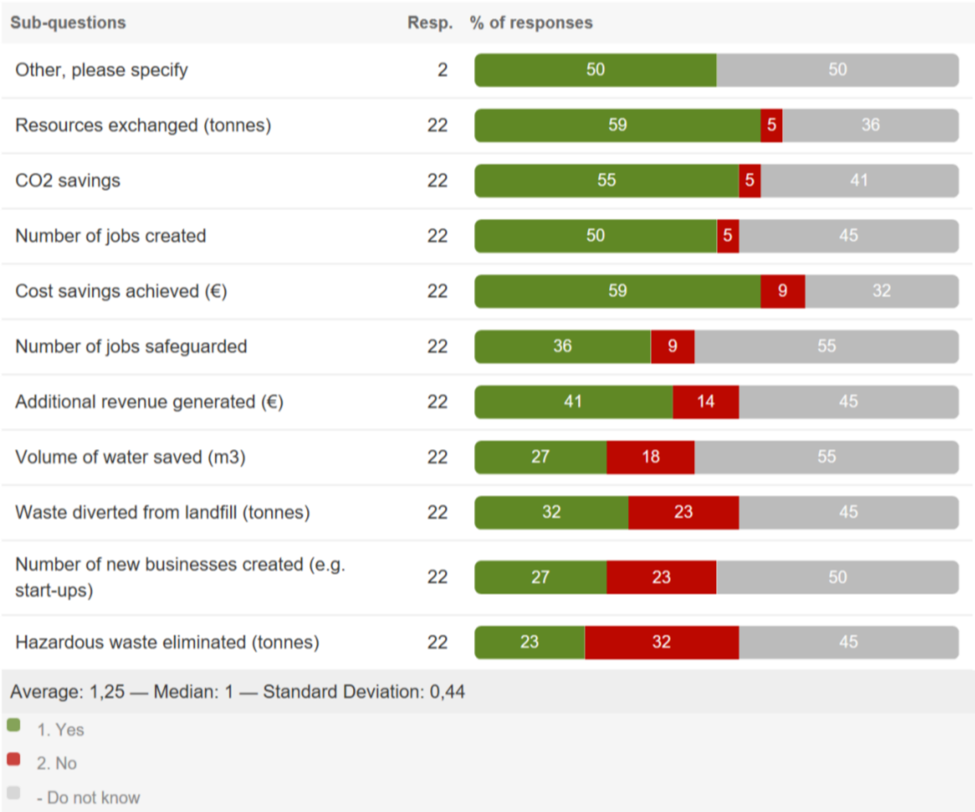
Source: survey with IS facilitators; multiple-choice question

4.3. Assessing impact of facilitation

The objective of facilitation activities is to generate impact through promotion of IS. Assessment of impact is key in determining whether: 1) facilitation plays a role in IS promotion; 2) whether cost-benefit analyses can justify policy intervention in this area. Here, the analysis considers solely direct support through funding of facilitation. Other policies directed towards setting adequate framework conditions will be discussed in section 7.

Facilitated networks have reported private and societal benefits derived from improved resource use. One of the limitations faced when assessing impact, as discussed above, is the lack of standardised frameworks and homogenised metrics to measure impact and gather data.

Figure 9 Results achieved by IS facilitators surveyed

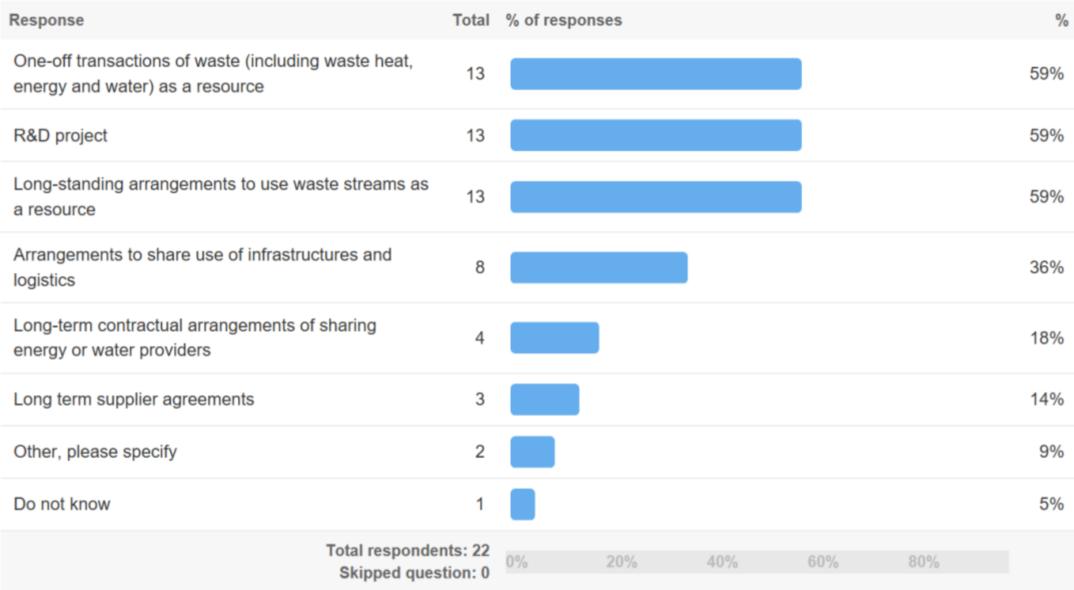


Source: authors, based on survey with IS facilitators; n=22; multiple-choice question

Evidence gathered in the survey and confirmed during interviews suggest that facilitation may have a positive impact on the triple bottom line of companies and regions. More than half of the nodes (59%) were able to report the fact that their main results included resources exchanged, cost savings achieved, CO2 savings (55 %) and jobs created (50 %). However, looking at **Error! Reference source not found.**, it is also extremely important to note the large grey area which are "unknown" benefits. Across all different categories of results, a high percentage of respondents (facilitators) did not know or were not aware of the results that have been achieved through facilitation. This is especially relevant in areas such as water, jobs created and new businesses. In the case of water, this may be related to the scope of some of the initiatives that is restricted to solid waste. New businesses and jobs are difficult to measure as impact may not be immediate and could be a considerable lag between intervention through facilitation and creation of new businesses and jobs.

Based on survey results, it is also important to note the variety of outputs of IS 'transactions' or of projects resulting from the cooperation facilitated between the members of the IS networks. The majority of the facilitators that replied to the survey (59 % or 13 out of 22 organisations) have achieved three types of transactions: one-off transactions of waste as a resource (including waste heat, energy and water), R&D projects or long-standing arrangements to use waste streams as recources. Some other nodes (8 out of 22 respondents) also support arrangements to share the use of infrastructures and logistics Figure 10.

Figure 10 Types of transactions/activities in facilitated IS networks



Response	Total	%
One-off transactions of waste (including waste heat, energy and water) as a resource	13	59%
R&D project	13	59%
Long-standing arrangements to use waste streams as a resource	13	59%
Arrangements to share use of infrastructures and logistics	8	36%
Long-term contractual arrangements of sharing energy or water providers	4	18%
Long term supplier agreements	3	14%
Other, please specify	2	9%
Do not know	1	5%

Total respondents: 22
Skipped question: 0

Source: authors based on survey with IS facilitators; n=22; multiple-choice question

Looking at evidence for a number of facilitated networks where data exist, the number of resources identified is generally large compared with the number of synergies that are completed. For example, in the case of the IS programme in Denmark, supported by the Danish Business Authority, 373 resources with potential were identified, however, only 147 were considered to have a symbiotic match. From those 147 potential synergies, 78 were granted support for feasibility studies through the grant scheme, with only 24 (31 %) having progressed through the idea to a qualified (technically and economically feasible), established (companies involved have entered the agreement phase) or implemented synergy stage (based on data provided by the Danish Business Authority). This proves that although the potential for IS is high, implementation is limited by a combination of factors which include technical, economic and social/policy elements. This is not unusual in the area of IS, with practitioners having suggested a rule of thumb of a 5 % success rate from initial identification of waste streams with potential.

Assessing the role of facilitation against self-organized activity is challenging because when IS activity has been facilitated it is difficult to argue whether or not the activity could have also emerged in the absence of facilitation. Studies unveiling IS suggest that IS activity may happen naturally between organizations and can go unreported. However, IS facilitation also seems to provide evidence for substantial untapped opportunities to turn waste into a resource or move waste up the waste hierarchy.

The survey also indicates that benefits of facilitation may be more far-reaching than just the resource transactions and may contribute to improving the firm's overall environmental performance, building new partnerships, creating new revenue streams and even changing business models towards more sustainable ones (see figure below).

Figure 11 Impacts of the existence of an organisation facilitating IS

Source: authors based on survey with IS facilitators, n=22; multiple-choice question

For a small number of initiatives for which quantifiable metrics are available and comparable, it is possible to provide a more accurate assessment of performance. The table below compares impact across different facilitated programmes. The table shows differences in network size and scale (based on network operative budget). A general overview suggests even short-lived networks were able to achieve relevant environmental and economic benefits (see Table 7). Landfill diversion and GHG reduction was significant in most networks. This was accompanied by costs savings and a range of other business benefits (including additional sales and private investment).

Table 7 Comparative performance assessment of IS facilitation programmes

	NISP Scotland	NISP Hungary	NISP UK	Romania ECOERG	Invest NI	PNSI	SMILE***
Period	2007-1011	2010-2012	2005-2012	2009-2011	2007-2017	2015-2017*	2016-2017
Network size		800+	15.000+	200+	1.900+	588+	1.581+
Number of synergies (realised)	127 completed	72 completed		200 synergies	448	958 potential	1.882 potential
Scope	regional	regional / national	regional / national	regional / national	national	regional / national	regional / national
Landfill diversion (t)	62.459	594,16	6.428.571,42	265.000	39.200	13.954,5	7.342
GHG savings (t CO2)	38.836,6	1875,67	5.571.428,57	65.000	34.000	1.081,5	
Virgin raw materials saved (t)		619	8.285.714,28		24.000	3.920	
Hazardous waste saved (t)			285.714,28		1.270		
Water savings (m3)		13.017,98	10.142.857,14				
Cost savings (Mill EUR)	0,93		172,85		2,77	0,25	1,25
Additonal sales (in mill EUR)	0,4				1,79	3,47	
Private investment (in mill. EUR)	1,602		243		0,211	0,037	
Jobs (number)						3	
Total Budget (in mil. Euros)	0,256	0,396	6,341	0,4403			0,15

***The programme has been running 2010-2017. 2010-2016 just as a web-based platform with little to no facilitation. 2016-2017 the network provided technical support. Budget is approx. €150,000 per year and about €600,000 in total. Here the calculations are based for 2016-2017 where there was technical support (comparable to the rest of the networks considered)

Source: Authors' own elaboration based on compiled data

As the programmes were operative for different periods of time ranging from two to seven years, had different scales and, overall, funding differed substantially, impact performance has been calculated based on €1 of funding per year. This allows for the cross-comparison of facilitated networks and provides indicative figures of the impact achieved by €1 of funding. As the networks assessed depended almost entirely on public funding, this provides an estimate of the ROI of public investment. Although the figures vary substantially across programmes, they indicate that landfill diversion was achieved at a relatively low cost, with €1 of funding achieving landfill diversion of a substantial amount of waste, ranging from several kilogrammes to 1 tonne. Even considering large variations of landfill costs across MS, this points to important cost-saving opportunities for the private sector. Similarly, GHG savings associated with landfill diversion and other reuse opportunities (i.e. waste heat) were also achieved at a relatively low cost, ranging from almost 900 kg CO2e reduction to 130 kg CO2e reduction per €1 of public investment. Considering the current price of carbon of €6.65 per tonne (September 2017), reductions also represent several thousands of potential private savings.

From the limited evidence available, it seems that other factors such as the size of the programme and its duration may affect its effectiveness. Larger and longer-term operating networks achieved relatively better results. This may indicate some economies of scale in the facilitation process (e.g. learning). This also seems to support the claim of facilitators interviewed suggesting more complex synergies may take several years to be implemented. Performance of the networks is also dependent on a number of different factors, including framework conditions, organisation of waste management in MS, waste and recycling infrastructures, regulation enforcement and actors' awareness.

Future research is needed to better understand how regulatory, social and organisational issues may affect the performance of facilitated activities.

For a small number of initiatives for which quantifiable metrics are available and comparable, it is possible to provide a more accurate assessment of performance. The main limitation of this analysis lies in the reliability of the data. Apart from the NISP initiative where results were audited by a third party, there is no evidence of third-party verification for the results of the other initiatves.

Table 8 Performance of IS facilitated networks (results per €1 invested)

	NISP Scotland	NISP Hungary	NISP UK	Romania ECOERG	Invest NI	PNSI	SMILE***
Landfill diversion (t)	0,22440	0,0015	1,0137	0,6017	0,1508	0,0613	0,0489
GHG savings (t CO2)	0,1517	0,0047	0,8786	0,1476	0,1308	0,0048	
Virgin raw materials saved (t)		0,0016	1,3066		0,0923	0,0172	
Hazardous waste saved (t)			0,0451		0,0049		
Water savings (m3)		0,0328	1,5995				
Cost savings (Mill EUR)	3,6328		27,2584		10,6692	1,1278	8,3546
Additonal sales (in mill EUR)	1,5625				6,9154	15,2844	
Private investment (in mill. EUR)	6,2578		38,3194		0,8115	0,1655	

Table represents amounts for €1 of investment per year.

***The programme has been running 2010-2017. 2010-2016 just as a web-based platform with little to no facilitation. 2016-2017 the network provided technical support. Budget is approx. €150,000 per year and about €600,000 in total. Here the calculations are based for 2016-2017 where there was technical support (comparable to the rest of the networks considered)

Source: author's own calculations based on compiled data.

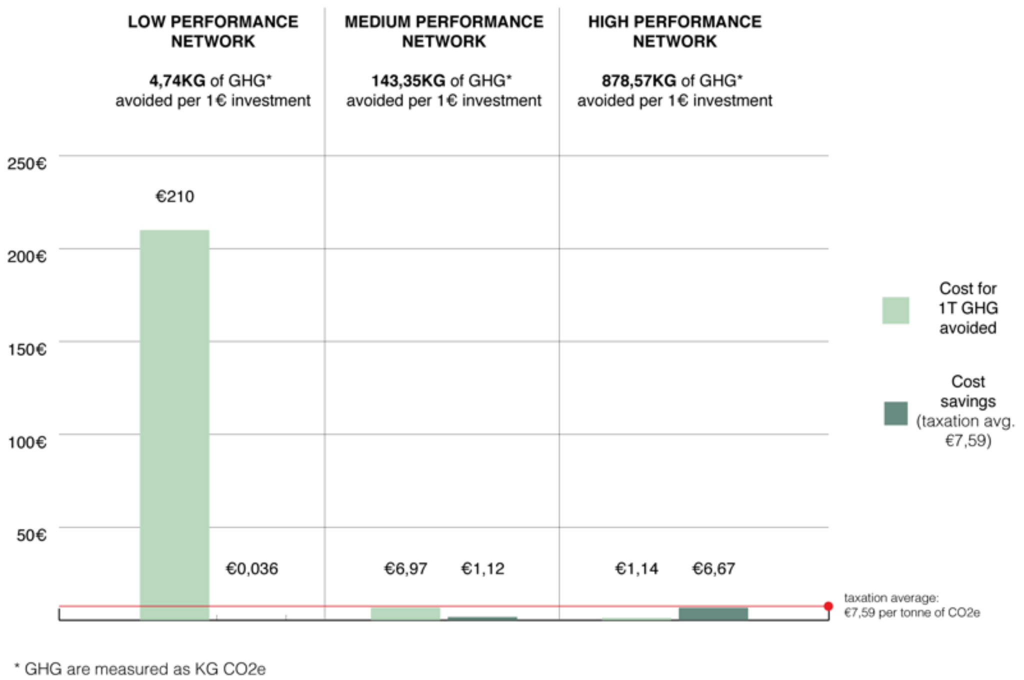
Based on the cross-comparison, Table 9 below provides benchmarks for high-performing, medium-performing and low-performing programmes, which are also illustrated in Figure 12 and Figure 13. These benchmarks do not take into account the stages of development of the network (e.g. it is likely that a network that has just started is unable to achieve in the first year of operation similar results as long-standing networks), the overall network structure (e.g. networks with very small numbers of members may not reach sufficient scale to perform at a high level) and socio-economic contextual features shaping framework conditions where the network operates. However, even without consideration of these important aspects, the comparison shows substantial benefits achieved at relatively low costs. The benchmarks may also provide indicative targets for newly-established programmes.

Table 9 Amount of landfill diversion and CO2 savings per €1 investment in IS networks

For 1EUR Investment	LOW	MEDIUM	HIGH
GHG SAVINGS (T, CO2e) per 1EUR	0.00475353	0.14759812	0.87857626
1 Tonne GHG avoided	€210	€6.77	€1.13
Landfill diversion	0.006133442	0.6017462	1.01374183
1Tonne Landfill diversion	€16.3	€1.66	€0.98
Cost savings (from carbon taxation 7.59€ at 29-11-2017)	€0.036	€1.12	€6.67
Cost savings (landfill tax- Average €80.75)	€0.49	€48.53	€81.75

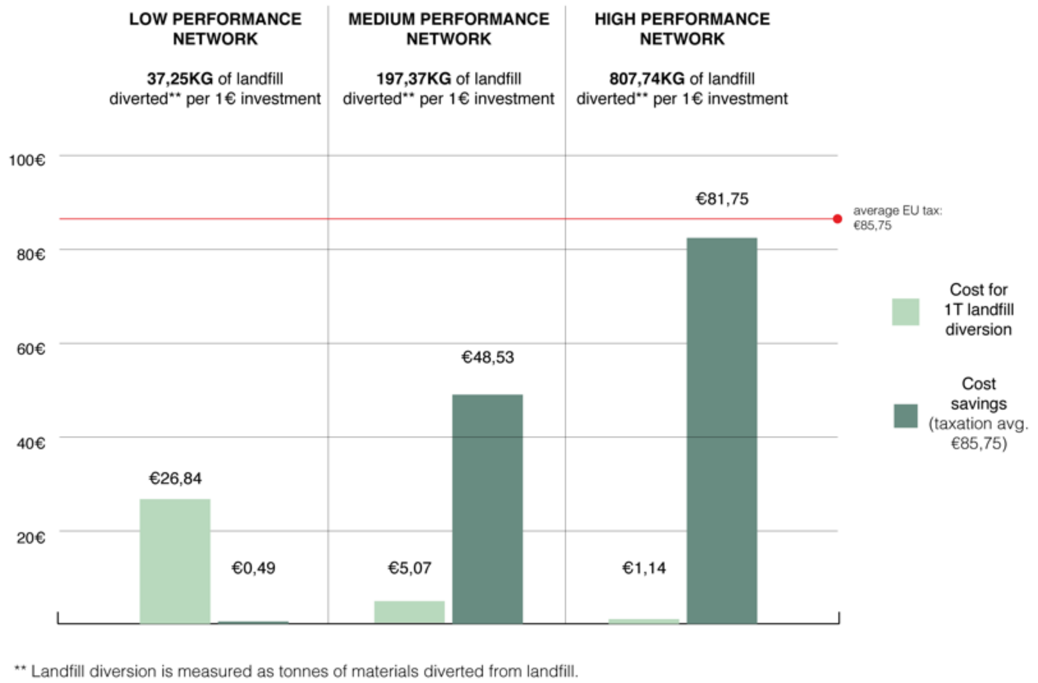
Source: own calculations based on primary data collected through the study.

Figure 12 Benchmarks for costs of reducing 1 tonne of CO2 and potential savings (from tax avoidance)



Source: authors' own elaboration based on compiled data

Figure 13 Benchmarks for costs of diversion of 1 tonne from landfill and potential savings (tax avoidance)



Source: authors' own elaboration based on compiled data

Table 9 highlights that facilitated programmes have contributed to win-win solutions where environmental targets have been achieved at relatively low cost, while also generating substantial cost savings for industry already in terms of cost avoidance with regard to environmental taxation.

Web-based trading platforms have not been considered in the cross-comparison for two reasons:

1) absence of reliable data about network performance and

2) for the very few cases where some data exists, the order of magnitude of impact cannot be compared to facilitated networks, due to its reduced scope.

An explanation of lack of monitoring of impact is that once the synergy has taken place, there is no incentive for companies to report the impact/benefits achieved. The main reason for lower impact is the complexity of synergy implementation that is surrounded by specific risk and uncertainties. Beyond very simple IS opportunities (where a waste or by-product can be directly reutilised by another company without any further processing), web-based trade platforms are unlikely on their own to unleash IS potential.

The case of the SMILE programme in Ireland is interesting in this respect. SMILE was initiated in 2010 as a waste trading system to promote IS and has over the years transitioned towards a more hands-on facilitated approach. The impact of the programme in terms of environmental targets achieved and private and social benefits generated has also evolved accordingly. SMILE facilitation is now provided on three main fronts: 1) a phone 'hotline' system, 2) a web-trading website and 3) technical support consultants (since 2016). Since 2010, SMILE has supported 1882 synergies and generated around 35 253 tonnes of landfill diversion and costs savings of over €6.4 million. Nevertheless, while the programe has grown substantially over the years, about 40 % of its impact – both in terms of landfill diversion and economic benefits, has been accrued in the last two years of operation (2016-2017), suggesting that the introduction of the technical support functionality significantly contributed to the identification and realisation of new synergies.

4.4. Network performance: self-organised vs managed IS

While network metrics such as number of members, number of resources and synergies completed were available in many cases, the quantification of the impact, although generally acknowledged, was in most cases not calculated and not reported. For a small number of initiatives for which quantifiable metrics are available and comparable, it is possible to provide a more accurate assessment of performance. The main limitation of this analysis lies in the reliability of the data. Apart from the NISP initiative where results were audited by a third party, there is no evidence of third-party verification for the results of the other initiatves.

Table 8 Performance of IS facilitated networks (results per €1 invested) above shows metrics for a number of networks. A complete list of networks and compiled results is provided in Appendix A. The great disparity of networks in terms of size, facilitated/self-organised and the fact that considering the absolute numbers of synergies also does not provide a clear quantification of impact (as synergies may be one off or continue over time, and volume exchange vary from a few tonnes to several hundred tonnes), does not allow for a consistent assessment of performance.

The table supports the findings from the mapping exercise, as self-organised networks tend to be smaller in size (in terms of number of businesses) but denser in terms of material/water/energy exchanges. However, it is also important to note that they have been operating for a longer period of time and, in most cases, economic benefits of IS transactions have been linked to stringent environmental regulations and internal business commitments to improve environmental performance. The type of synergies also is highly dependent on the industrial structure prevalent in the local and regional area.

From the analysis, it is difficult to derive an absolute answer to the issue of whether self-organised networks perform better or worse than facilitated ones. Unveiled self-organised networks have operated for a longer timespan and, in many cases, have reached some sort of institutionalisation. The case of Kalundborg is generally viewed as a model for industrial symbiosis but there are a number of other examples in northern and central Europe. In the case of Styria (Austria), the original network of 28 companies generated over one million tonnes of by-products, with over 70 % being recycled through bilateral agreements between firms. Recently, some smaller scale examples of industrial symbiosis have also been identified in other MS. Domenech and Davies (2011) unveiled IS activity in a steel-cement cluster in Spain, and Daddi et al. (2017) quantified environmental impact reduction associated with IS activity in an Italian tannery cluster. In most cases, pressure from the regulatory framework, requirements from the supply chain and company policy requirements incentivised the IS projects. In the case of Italy, the cluster was mainly composed of small and micro businesses but IS activity emerged from the sharing of infrastructures, generally linked to water treatment, with high investment costs. In the case of Kalundborg, it was water scarcity that led to company cooperation. It should also be noted, however, that although public actors were not initial leaders of the projects, both in Kalundborg and the small Italian cluster they provided support to find collaborative solutions. In Kalundborg the district heating project developed in partnership with the municipality and in the

Italian cluster projects developed as PPPs, where local and regional government contributed to the investment.

So, one may conclude that self-organised activity is more likely to emerge under institutional frameworks that incentivise reuse and recycling activity by: 1) creating negative incentives to landfill of waste (landfill taxes) or enforcing recycling (landfill bans) and 2) creating positive incentives to recycling (i.e. pressures from supply chain and stringent enforcement).

In the case of self-organised networks however there are only examples of those that have succeeded, with virtually no information about those that have failed, because incentives were not strong enough, cooperation between companies did not work or they were unable to solve the potential problems they encountered (technological, regulatory, etc.). There are also examples of facilitated networks that work and manage to achieve expected outcomes and others that fall short of expectations. NISP UK had a large budget and operated nationally providing remarkable achievements in terms of waste diverted from landfill. This however happened in the context of a landfill tax escalator that provided incentives to companies to engage in IS projects. Long-standing networks such as Northen Ireland Industrial Symbiosis and SMILE prove that long-standing facilitation structures continue to provide positive outcomes. Other shorter-term initiatives such as networks in Hungary and Romania achieved outcomes but found it difficult to compete with the low costs of landfilling. Large recent initiatives such as the Italian National Network (coordinated by ENEA) and the PNSI in France are too new to assess. Denmark launched in 2013 a national network that operated for a few years. The network managed to achieve targets with regards to number of resources and potential synergies identified, but found it difficult to reach the status of "completed synergies", those implemented, for many of the 78 projects that received funding for feasibility studies. Also, the lack of impact assessment of the synergies made it difficult to assess the real impact of the programme.

Also whether self-organised or facilitated activity is likely to work depends greatly on the specific context and needs of different areas. Facilitation, as discussed above, addresses some of the barriers to IS development, fundamentally the barrier of information both with regards to: 1) information and awareness of potential areas of opportunities and 2) identification of potential partners, in many cases beyond the supply chain and sector the company operates in. Facilitation can also partly contribute to overcoming technical/technological and regulatory barriers. However, both self-organised and facilitated activity rely on the relative value of IS activity for the business. This "value" does not necessarily have to refer solely to economic calculus but also to social and environmental objectives pursued by the company. Both findings from the survey and interviews have emphasised the lack of a sufficiently strong economic/financial incentive as a main barrier to IS. This is generally linked to the low marginal value of waste and secondary materials.

Economic viability/feasibility of IS projects is largely shaped by the institutional framework surrounding waste. This includes the price of competing options (e.g. waste landfilling) but also the perception of other more difficult to quantify benefits (e.g. company image). Both in the case of Kalundborg and Italy, self-organised activity has emerged as a collaborative solution to a collective problem, which has then been extended to other areas. Facilitation activity tries to artificially recreate space for communication and connection, with differing degrees of success. The question is thus not so much about comparing performance of self-organised and facilitated activity but rather to investigating whether self-organised activity would have emerged without facilitation. Also important is to assess facilitation against other forms of intervention: 1) to achieve environmental targets and 2) to do that with associated social and economic benefits. With the limited quantitative evidence available in the area, facilitated programmes seem to have achieved substantial environmental benefits at a relative low cost, while generating some economic and social benefits in terms of private investment, spin off activities and jobs secured or created.

As recycling targets get tighter in Europe, the role of waste management companies has partly taken over some of the space of IS facilitation (Velenturf & Purnell, 2017). However, objectives and scope of waste management companies and IS facilitation differ substantially. As mentioned earlier, waste management generally only deals with solid waste and issues such as water and energy are generally not considered. This means that solutions and synergies across different systems (water as energy; waste heat, etc.) are left out of the equation. Also, as profit-seeking organisations, waste management companies focus on optimisations according to a number of parameters that include evaluation of costs and options, which do not necessarily have to strictly adhere to the waste hierarchy or Circular Economy (CE) principles. Also, more established solutions may be preferred to more innovative ones. Facilitation can bring innovation to the waste management sector, especially for smaller players, and can open the range of possibilities for companies in terms of waste solutions.

4.5. Conclusions on assessing IS facilitation

The assessment of facilitation in Europe has provided some interesting insights to the analysis of IS policy options. As discussed above, the results are obtained based on the survey and interviews with representatives of the IS initiatives. Since the data presented in this study has been self-reported by the IS facilitators without any possibility of independent verification, the quantitative results presented should be treated with caution. However, they provide an indicative basis for assessing performance of existing IS facilitated initiatives. The following conclusions could be drawn:

Firstly, facilitation programmes have varied substantially in terms of scope and scale. There are a handful of networks that have operated for a long time supported by governmental funds and many more examples of networks that have worked only for a limited period of time linked to specific funding streams. There is no evidence of operative fully commercial facilitation activity in Europe.

Secondly, a key problem to assess the performance of facilitation is the lack of harmonised frameworks for assessment and the very limited quantitative data reported by facilitators. For those initiatives for which there is comparable data, evidence suggests that facilitation achieved environmental objectives of landfill diversion and GHG savings at a relatively low cost and with some additional benefits for companies in terms of savings in raw materials and additional sales and revenue sources. However, there is no information about the transactional costs associated with the benefits in terms of time and expertise. The analysis also suggests that some IS projects may take a long time from inception (idea stage) to realisation, which may also create a disincentive for companies that need short term solutions.

Comparing performance of self-organised and facilitated activity is extremely difficult as the scale, scope and types of transactions differ substantially. The analysis suggests that there are examples of self-organised IS activity in Europe. These are generally quite localised and initially driven by a collective problem or opportunity. There are also examples of IS activities in industrial parks led by an anchoring activity. Self-organised activity generally develops over a long period of time and is the result of a number of different factors including scarcity of a specific resource, pressures from the regulatory framework of from the supply chain.

Attempts to commercialise facilitation have generally not worked or only at a very small scale, which is due to a combination of factors that will be addressed in section 6. So the question of whether direct support can be justified or not needs to take into account the environmental and economic targets that have been set and how governmental support can best be organised to achieve those targets in the most efficient manner.

5. THE MARKET POTENTIAL FOR INDUSTRIAL SYMBIOSIS

5.1. Aims of the market analysis and limitations

Understanding the market potential of industrial symbiosis can be highly valuable in motivating policy-makers to look at ways in which they can support its development and for companies to look further into the opportunities it can provide. Therefore, demonstrating the environmental, economic and societal benefits of existing intiatives and their (untapped) potential for replication would be highly beneficial to justify policy action in the area.

However, as discussed in the mapping section, defining the market size of industrial symbiosis is a complex task. On the one hand, IS activity may be unreported. Businesses may be motivated to engage in beneficial transactions involving waste or underutilised resources driven by economic opportunities. It is likely that close examination of industrial clusters in Europe would 'unveil' IS activity currently unreported. Moreover, as analysed in the previous section, most data on IS performance generally come from facilitated initiatives. This data, with some exceptions, tend to be fragmented, inconsistent across iniatives and time and difficult to validate. Another limitation is that data tend to be collected at one point in time while continuous updating and monitoring is generally absent, with the exception of longer run facilitated programmes.

The mapping exercise provides some estimates of actual benefits generated by IS networks in Europe. The data seem to suggest that win-win-win opportunities have been achieved, however, any extrapolation from IS network data from individual networks to understand market potential faces several restrictions, as data points are few and tend to be concentrated in specific regions.

To this end, the section provides an overview of existing work that has attempted to quantify this potential and then carries out a new synthesis and data analysis to provide new insights on the potential value of IS approaches. The focus of the analysis is on: a. potential revenues from currently disposed secondary materials and b. cost-avoidance opportunities associated with landfill diversion. The analysis is complementary to the mapping exercise that provides local-specific data on different programmes and iniatives from a broader perspective, which also considers environmental and societal benefits.

5.2. Current state of IS market and research on IS market potential

This section provides an overview of the market potential for industrial symbiosis in Europe. Although IS has been regarded as a win-win-win approach, there is limited quantitative evidence on its potential. This section provides an estimation of potential from a combined value generation and cost avoidance perspective.

Current European IS market size and potential are unclear

From a wide-ranging review of industrial symbiosis literature, we find that the number of studies directly assessing the market size and potential of IS is limited. The two key studies with a specific focus on IS-type activities were those carried out for the European Commission in the years prior to this work, which constitutes the basis for this report, and still remain among the most comprehensive sources:

- "Treating Waste as a Resource for the EU Industry: Analysis of Various Waste Streams and the Competitiveness of their Client Industries"[9], provides an analysis of market typologies of waste streams. Based on the volume of non-recycled waste and its total market value, potential to increase recycling and strategic value, the waste streams with most potential for IS would be iron and steel, paper (excluding packaging), batteries (excluding automotive batteries), tyres and electronic waste (WEEE). The potential of IS is addressed indirectly, by analysing the entry barriers to IS for these sectors and providing a few estimates of waste generated and recovery rates for some of those types of waste, but no real estimates of market potential in euros.
- "Analysis of certain waste streams and the potential of Industrial Symbiosis to promote waste as a resource"[10] provides comprehensive analysis of waste streams in multiple sectors. It focuses on the food waste, construction and demolition (C&D) waste, plastic waste, wood waste and non-scrap metal waste streams as most interesting for IS. But whilst waste streams, sources, market conditions and treatment practices were analysed, the study did not progress to place a value on the market potential of IS in these sectors.

In summary, we can conclude that although these studies contain a host of qualitative information in terms of drivers, barriers and potential for IS in various sectors, and some quantitative information on the volumes of waste being generated and rates of waste recovery, they do not significantly quantify the market size or potential of IS in the EU. This highlights a continuing gap in macro-level analysis of IS market size and potential, and indeed justifies the rationale for this work.

A plausible approach to compensating for this missing data would be to use individual IS initiative-level data in different MS based on the mapping exercise undertaken and, using assumptions, estimate the potential for replication and/or scaling up of the existing IS approaches. This approach was adopted to calculate the IS potential provided in the COWI report (2011). In this case, market potential was estimated extrapolating the NISP results to Europe, controlling by GDP. The report estimated that an investment of EUR 250 million (as operating costs of the programme) would generate savings of EUR 1 400 million. And additional sales (as additional turnover) of around EUR 1 600 million, as well as environmental benefits of 52 million tonnes of landfill diversion and 45.5 million tonnes of CO2 reduction. Thus, €1 in investment could provide around €12 in benefits to business (combining cost savings and additional sales). This rough estimate is based on one single data point - NISP - and does not account for differences in economic structure, waste management capacity and other framework conditions.

Indeed, data gaps are a crucial issue at IS initiative level, with little work having been carried out to quantify the impact and benefits of existing IS initiatives implemented in the EU, as the survey and mapping have revealed. The handful of examples where quantitative data is available have been discussed in the mapping section. Most studies refer to some of the paradigmatic cases summarised in the mapping section which include NISP, Kalundborg and other smaller-scale initiatives. Cross-comparisson of case studies in previous section has shown that: 1) there is potential for IS and potential for cost-savings and environmental benefits; 2) Patterns of development of IS activity depend on a combination of factors, including policy levers and regulation; 3) data sources are extremely

[9] ECSIP (2013) Treating Waste as a Resource for EU Industry: Analysis of various waste streams and the competitiveness of their client industries Available at: https://ec.europa.eu/docsroom/documents/3866/attachments/1/translations/en/renditions/native

[10] Bilsen, V. et al, 2015. Analysis of certain waste streams and the potential of Industrial Symbiosis to promote waste as a resource

limited, which severely constrains the opportunities of quantitative analysis based on IS network initiatives.

In summary, from IS focused sources, it is clear that the data directly focused on estimating the IS specific impact and potential remains quite limited at both macro and micro (initiative) level and therefore it is difficult to draw precise conclusions for the rest of the EU, or to say much about the specific geographic potential. What can be said from this limited data is that replication of similar programmes in other EU Member States would likely deliver significant new cost savings and sales, but that these could total anything from tens to hundreds of millions of euros each year. There has also been little if any work investigating specific clusters, sectors or regions where the conditions are opportune to replicate the existing intiatives.

Some insights can be gained from the related area of circular economy

More comprehensive research has been carried out in the related area of circular economy (CE), where market potential has been studied in a number of recent publications. Also, industrial symbiosis has been recognised as an important tool for the CE, from which one could deduce that some of the CE potential gains are associated with IS activity. This can also provide some useful indirect indications of market potential, noting the fact that CE initiatives encompass a wider set of activities than IS, while IS contributes to CE. For the CE examples of market potential estimates include:

- The EC's Roadmap to a Resource Efficient Europe[11] points out that improving the reuse of raw materials through greater 'industrial symbiosis' could save €1.4 billion a year across the EU and generate €1.6 billion in sales.
- Estimates that a shift to a circular economy in the areas of mobility, food and the construction sector would generate annual primary resource benefits for Europe of as much as €0.6 trillion per year by 2030, and even greater non-resource and externality cost benefits.[12]
- An expansion in circular activity based on the current development path towards a circular economy, shows that the potential labour market impact in Europe to 2030 is to create 1.2 million jobs with long-lasting benefits from a reduction in unemployment by around 250,000 in total (gross jobs estimates from country to country vary significantly i.e. 328,000 new jobs in Germany vs. -/+1,000 in Malta or Cyprus)[13].

Clearly then the circular economy could have highly significant market potential and economic benefits in Europe, within which IS could be expected to play a role. Nevertheless, 'ready-made analysis' at this macro-level on IS specific market size and potential is missing.

Taken together, the analysis of data relating to IS and circular economy is highly suggestive of large potential savings and market potential but remains thin on details and numbers. In the following sections we will collect and process existing data using new approaches to expand upon the existing evidence base.

[11] European Commission (2011). Communication on Roadmap to a Resource Efficient Europe. COM/2011/0571 final

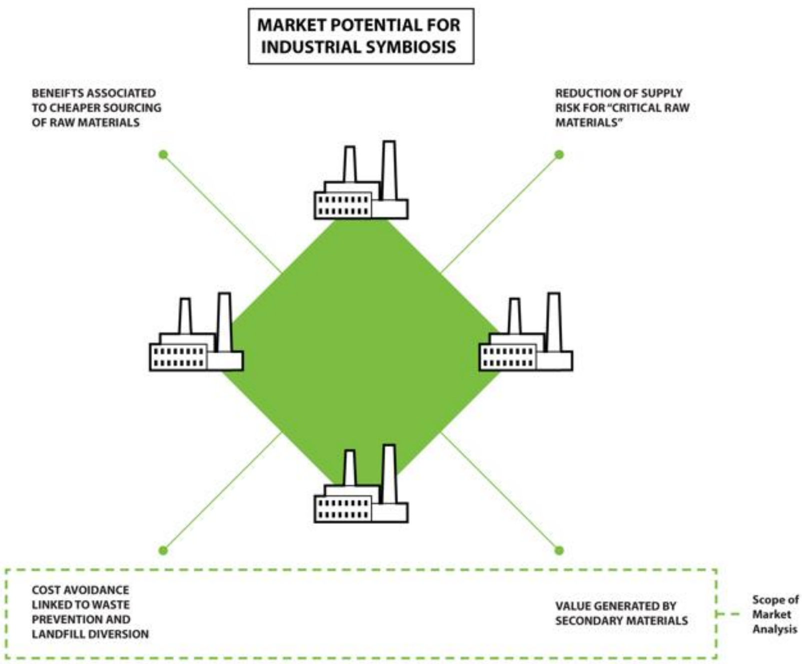
[12] Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment (2015) Growth Within: A Circular Economy Vision for a Competitive Europe

[13] Mitchell, P.; James, K. (2015) Economic Growth Potentials of More Circular Economies; Waste and Resources Action Programme (WRAP)

5.3. Market analysis methodology

As indicated above, this study aims to fill an existing gap by providing some initial estimations of market potential for IS. In the absence of IS specific data, this study proposes a two-way methodology to estimate market size: 1) estimating the positive value of wasted resources that could potentially be reutilised (though estimating the value of currently disposed priority waste streams) and 2) estimating the cost-avoidance opportunities associated with landfill diversion (cost savings for companies). This evaluation however has its own limitations as it does not account for the potentially strategic contribution of IS to reduce costs (and environmental impacts) associated with the sourcing of primary raw materials and supply risks associated with those considered 'critical raw materials' (see Figure 14 below).

Figure 14 Illustration of market analysis methodology



Source : authors

Limitations

The approaches used to estimate untapped market potential are top-down and based on general simplifying assumptions meaning that there are also specific limitations that should be taken into account:

- The main limitation of the estimation of market potential is that it focuses on the residual value of waste, but does not account for potentially larger opportunities linked to resources not becoming waste. The Waste Framework Directive of 2008 already considered the terms 'by-product' and 'end-of-waste criteria', providing a legal framework for utilisation of industrial by-products. Unfortunately, transposition of these instruments varies a great deal between MS, as does the interpretation of their scope. Data on actual type and tonnage of resources which have been given the status of 'by-product' or 'end-of-waste' is not immediately available for most MS, limiting the opportunities to base the analysis on this.

- Calculated estimates represent a maximum potential if all currently untreated, landfilled or incinerated waste could be recovered – clearly there are practical and economic barriers to achieving this, meaning the actual potential will be lower.
- The values do not consider the material losses and costs associated with the repurposing of the waste as a secondary raw material (e.g. the costs and efficiencies of the recycling process), which will be incurred if waste is diverted from landfill and use as a secondary material.
- The value assumptions are based on price indications from secondary raw material markets and suppliers. A single price assumption is used for a particular waste stream, despite the fact that the waste stream may encompass multiple types of waste with quite distinct properties and qualities and therefore different recovery possibilities and values. The price assumptions also often stem from English language sources and therefore have a bias towards the UK market. This may not reflect the EU market as a whole.
- Secondary raw material markets are quite volatile in general, with prices also heavily dependent on the evolution of primary market prices for globally-traded commodities. This may create incongruences where the price of recycled materials is higher than those of primary materials. For example, if the price of oil decreases, this may have a knock-on effect on prices of recycled plastics. However, as the cost associated with the recycling processes need to be covered, recycled prices may not be able to compete with the price of non-recycled plastics in a context of low oil prices.
- While the table covers a wide range of materials and waste streams, it has not been possible to cover all possible waste streams, therefore other materials may also have significant potential but not be included within the table (e.g. steel).
- The values that are provided are only the valuation of a single waste stream, rather than of a whole IS network or system, in some cases the waste stream may not be particularly suitable for IS.
- There are technical and infrastructural limitations to the reutilisation of certain types of waste materials. Although the study departs from the current maximum level of recycling by type of waste stream, there may be significant variation in the actual composition of waste streams by MS, depending on the specific sources and characteristic production processes in different MS.
- The potential is also significantly influenced by the availability of appropriate treatment infrastructures in the MS or neighbouring countries, which may determine the real recyclability potential of some waste streams.
- One important limitation of the approach as a whole is that it does not consider potential uses of resources before they become waste. The market potential linked to the prevention of waste and full reutilisation of 'by-products' is extremely difficult to estimate as there are no relieable databases that monitor transactions of by-products in the industry.

Future studies should address the market potential associated with upstream opportunities to use resources (by-products) before they become waste or after they achieve end-of-waste status. Due to differences in the interpretation and transposition of these instruments by MS, and as noted in the policy recommendations, this is an area where further EU guidance and hamonisation would be desirable. This should be accompanied by requirements to report this data to EUROSTAT. Future research should review common applications of the 'by-product' and 'end-of-waste' across MS and explore market potential associated to widespread applications.

Calculations of market potential from the two complementary approaches proposed are presented in next sections.

5.4. Market potential: waste stream potential approach

This approach is based upon the review and analysis of existing primary and secondary waste streams data, existing studies and expertise of the project team. The framework for the analysis is based on the Circular Economy Package priority waste categories (namely plastics, food waste, critical raw materials, construction and demolition waste, biomass and bio-based products) and the key waste streams within those categories. Gathering data on specific waste stream volumes, combining this with price data and then scaling to the EU28 level can provide insights, particularly into:

1. The scale of the market potential for secondary raw materials and therefore IS;
2. The specific sectors and waste streams where IS could be most valuable and relevant.
3. Where continuing data gaps exist, and further research would be needed to make an assessment of the market potential for IS.

The analysis of waste streams has been compiled into an original table – summary table in this chapter – an extended table with the full calculations and references to studies where the information originates can be found in Annex A.

Results of the analysis of waste streams for determining industrial symbiosis potential

The following paragraphs elaborate on the origin (sector) of each of the major waste streams, its availability (volume and complexity), what each waste can be used for (applications) and the value we estimate based on our price assumptions.

Plastics – In Europe over 40 % of plastics are used in packaging, 20 % in construction and less than 10 % by the automotive industry. Plastic waste also originates from disposed furniture, household appliances and agricultural products. According to Eurostat data from 2014, this consumption leads to 17 million tonnes od plastic waste each year. Although recovery rates of recycled plastic are relatively high (to be used back in the sectors in which the waste is originated), this is hindered by the diversity in plastic types – from some highly recyclable or reusable types (PET and PP) to others that are hardly recyclable (PVC). If the approximately 6.8 m tonnes (40 %) of untreated, landfilled and incinerated plastic waste was to be recovered then this could, at the Eurostat trade prices of around €250-350 per tonne[14], be worth **up to €2.4 billion per year[15]** and would represent a doubling of the existing market. In reality only part of this would be economically recoverable for IS.

Food – According to Eurostat data from 2014, 77.4 million tonnes of food waste (vegetables or animal food) are generated in the EU primarily at the consumer and distribution levels of the chain, followed by processing and in the last place production.[16] The recovery rates of treated food waste are high (90 %), with food

[14] Source: Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Price_indicator_and_trade_volume_for_plastic_waste_in_EU-28_till_December2013_update3.PNG

[15] Own calculation based on market prices and volumes as described.

[16] FUSIONS (2014) Report on review of (food) waste reporting methodology and practice

waste being used as a resource for animal feed, composting, the production of bio-energy, the production of bioplastics, pharmaceutical and nutraceutical products. Studies have suggested that the introduction of compulsory separated collection and biological treatment would result in **€100-425 million per year** (2013-2020) net benefits (80 % in the form of environmental improvements) across the EU[17].

WEEE – There is no recent Eurostat data on the volumes of WEEE produced in Europe, but data from other sources estimates that in 2013, WEEE streams amounted 9.5 Mt, with just 3.3 Mt (35%) collected for treatment.[18] This makes WEEE the least collected waste stream. WEEE applications are mostly limited to the electronics sector. An economic assessment of WEEE claimed a market of up to €2.1 billion based on current levels of WEEE, increasing to €3.7 billion in future (Cucciella, F., et al, 2015). WEEE is an important but complex waste stream to process, with potentially valuable quantities of critical raw materials recoverable from WEEE. As end-of-life products, rather than by-products their direct relevance to IS is limited, but for WEEE processors there may be opportunities.

C&DW – Construction and demolition waste is heterogeneous in type (including concrete, bricks, tiles, ceramics, roofing, insulation, wood, carpets, plastic pipes, organics, metals, gypsum, glass, hazardous waste, and many other miscellaneous items) and the proportion of particular waste types in the waste stream varies considerably between Member States, as well as from building site to building site. The largest part by volume is mineral materials and non-hazardous mineral materials disposed of at landfill are also the largest available waste stream for recovery and use in IS. C&DW streams amount to 297 million tonnes (according to Eurostat data from 2014), making it the largest waste stream in terms of volume, of those considered here. The heterogeneity of the waste stream is also a factor in differences in the estimated volumes of C&DW and how it is treated, with other sources estimating C&DW volumes of 450-500 million tonnes per year.[19,20] Eurostat reports high rates of treatment (94%) of C&DW and high rates of recovery (88 % of the 94 %) in this treated waste. However, some parts of industry report considerably lower numbers. For example the aggregates sector estimates current recovery rates of 196 Mt of materials for use in new materials, equivalent to around 40 % of the (higher) estimates of C&DW volumes available.[21] If this proportion could be increased to 75 % of produced C&D waste, the market would increase from around €0.8 billion to €1.4 billion per year, a potential growth of €0.6 billion, with the promise of further growth in future as projected waste streams also grow[22]. It should be acknowledged that this potential would be significantly lower if Eurostat data were applied. There are also additional complexities within the sector, such as the high concentration of SMEs which complicates the possibilities of increasing recovery rates and free up waste streams for IS.

Textiles – Eurostat data of 2014 reports 2.3 million tonnes of textile waste in the EU. Although treatment and recycling and recovery rates are relatively high (>80% each) there remains a balance waste stream of untreated and landfilled waste totalling around 0.8 million tonnes. Other sources suggest the total could be higher, estimating 1.3 million tonnes of unused clothing and textile resources annually with recycling potential remain landfilled, an equivalent of €56 million on EU landfill

[17] PPi4waste project deliverable - D2.4 State of the Art of Emerging Solutions- based on 2 scenarios of bio-waste collection and removal from treatment facilities, from 36.5%-100%.

[18] http://closeweee.eu/

[19] ttp://hiserproject.eu/

[20] CEMBUREAU (2016) Cement, concrete & the circular economy

[21] http://www.uepg.eu/statistics/estimates-of-production-data/data-2015

[22] Potential based on an assumed average value of €4/tonne for recycled aggregates. Calculated based on 2660 Mt production (EU28+EFTA) and €15 billion turnover per year for the industry. Value per tonne discounted by 25% and rounded to account for sometimes lower quality/desirability of recycled materials. Derived based on http://www.uepg.eu/statistics/current-trends

taxes that could be saved.[23] Based on an average price for used textiles of €250-350/tonne[24] an estimated market potential of up to €270 m can be estimated. This waste stream is probably the one with the widest array of applications, ranging from plastics, to construction, to industry, to the automotive industry, to agriculture, to energy recovery, to rubber industry, to energy industry and to civil engineering.

Wood – Wood is the largest biomass waste stream in terms of volume, amounting above 50 million tonnes in 2014 (according to the Eurostat). Wood waste is often treated (86%) but around half (46%) of the treated waste is not recovered and is disposed of at landfill. Part of the reason for this are the low prices available for wood waste, with average prices ranging from around -€60 up to €90/tonne[25,26]. The low – and sometimes even negative – prices per tonne of waste wood suggests a relatively low market potential for this material. However with high volumes available and if prices were at the high end of the range this could still be a significant market worth up to €2,700 million per year if all non-recovered waste were to be used. In reality the available waste stream is very likely much less as wood waste is often 'contaminated', which can be as simple as being painted or treated, or potentially containing nails or other metals. Wood waste can find a second life in a host of applications for instance timber products, paper pulp for packaging, hygiene paper, animal bedding, energy recovery, building material, floor covering and pin boards.

Used oil – In monetary terms, used cooking oil waste holds the biggest market potential from the biomass and biowaste category, which has been estimated to be worth up to €1.6 billion. Currently, Eurostat data shows that collection and treatment of the annual 4.2 million tones of oil waste generated is not very common (56 %), although recovery rates for treated waste are high (86 %). There is therefore a good case to be made to improve collection and treatment of this waste, which can be applied in the chemical industry or to generate energy.

In summary, the treatment and recovery rates vary from waste stream to waste stream – from over 80 % collection rates for textiles, aluminium (from construction and automotive sector), mineral waste (from the construction sector) batteries and accumulator waste and wood waste to just 56 % for used oils and 35 % for WEEE. However **waste treatment effectiveness also varies** for every waste stream – recovery rates range from 80 % or more for plastic waste, animal and mixed food waste and vegetal waste, mineral waste from C&D, textiles, used oils and batteries and accumulator waste, through to less than 50 % for wood, rubber and aluminium. The table also illustrates how applications of different waste streams vary in number and level of possibilities. Whereas closing the loop for critical raw materials (WEEE, aluminium, solar panels) means they stay in the sectors where they have been generated, food waste, plastic waste and perhaps to an extent construction waste can be applied in a wide range of sectors after treatment or/and recovery. As noted above in the latter case, given the nature of the sector it can be expected that organising the supply chain and building relationships between businesses across sectors would be more complex and challenging.

The volume of available waste, the gap between current waste treatment levels and full treatment as well as the price of the secondary material in question are amongst the critical factors in determining the maximum

[23] COWI (2011). Economic analysis of resource efficiency policies. A study commissioned by DG Environment - http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/economic_analysis.pdf

[24] http://www.letsrecycle.com/prices/textiles/

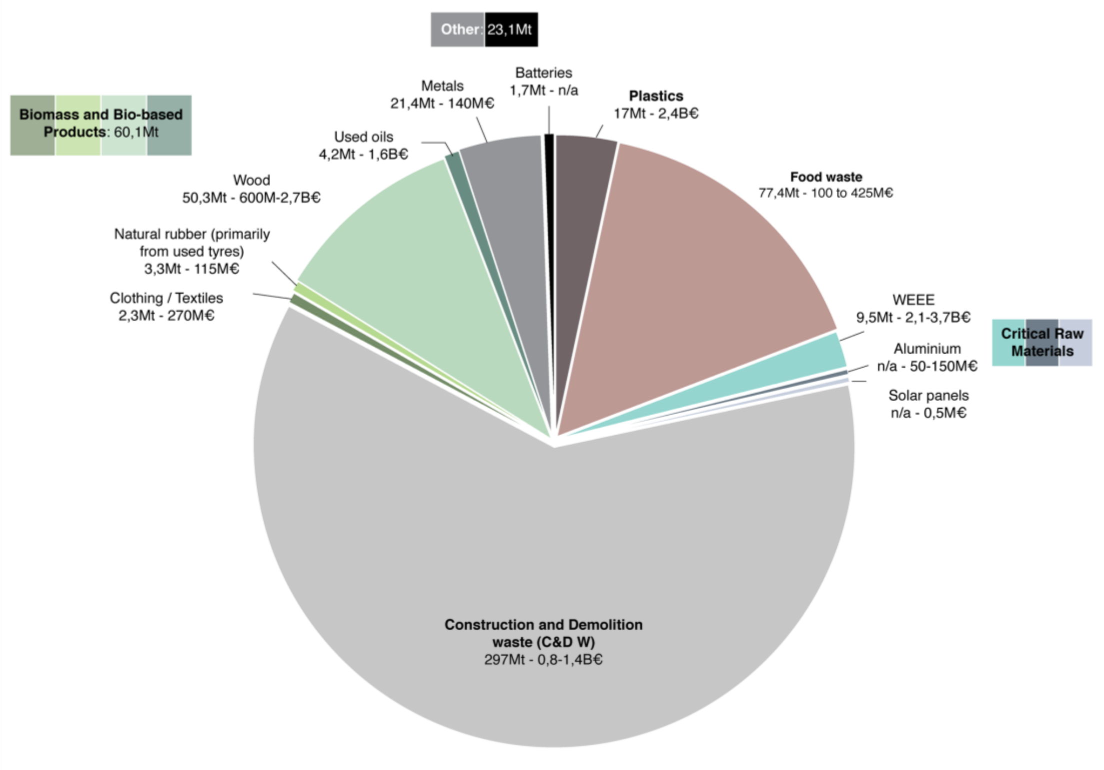
[25] http://www.wrap.org.uk/content/new-gate-fees-revealed-wrap-show-changes-market and http://www.letsrecycle.com/prices/wood/

[26] http://bioboost.eu/uploads/files/bioboost_d1.1-syncom_feedstock_cost-vers_1.0-final.pdf

market potential of different waste streams. Based on these criteria, **the waste stream with the highest IS market potential is plastics**, where currently untreated waste could have a potential of up to €2.4 billion per year and would represent a doubling of the existing market. This is followed up by used oils which could fuel a market worth up to €1.6 billion and currently non-treated C&DW up to €0.6 billion. WEEE is likely to have high IS market potential based on its current market size. There is also an important business case to be made for both **wood waste and food waste, whose estimates vary significantly but the main conclusion is that the savings and benefits are potentially very high**. The market potential for the former could be as high as €2.7 billion per year mainly due to its availability in large volumes, but it could also be very low as prices are also often negative, with the waste stream attracting a disposal charge. Food waste has a potential of €100-425 million per year stemming from the processing of currently uncollected waste.

Error! Reference source not found. and Table 10 provide an overview of the estimated scenarios of potential volumes and potential value of IS activities that could be achieved by industry. As a result of the limitations discussed in Section 5.3, the values provided in Figure 15 and Table 10 should be treated as indicative maximums only, as each includes significant price, market and volume uncertainties.

Figure 15 Estimated potential volume and worth of IS activities by industry



Source: authors.
Note: The values provided should be treated as indicative maximums only, as each includes significant price, market and volume uncertainties.

Table 10 Overview of market potential estimate per sector - summary table

CE package priority sector	Waste stream	Volume waste stream	Waste treatment	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
Plastics	Packaging, furniture, household appliances, electric and electronic goods and agricultural products	17 Mt	75 % was treated. Of treated waste: 80 % recovered 6 % landfill/disposal 1 % incineration/disposal 14 % incineration/energy recovery. 6.8 m tonnes untreated, non-recovered	• Plastics/packaging sector • Construction industry • Agriculture • Electronics industry • Automotive industry • Textile industry	If the approximately 6.8 m tonnes (40 %) of untreated, landfilled and incinerated plastic waste was to be recovered then this could be worth up to €2.4 billion per year and would represent a doubling of the existing market.
Food waste	Vegetable and animal food waste, i.e. dairy, meat, legumes and seeds, cereals, breads, rice, vegetables and fruits, originating from Primary Production (from farming), Processing (from food manufacture), Distribution (supermarkets), Consumer (households).	77.4 Mt	80 % was treated. Of treated waste: 90 % recovered 3 % landfill/disposal 1 % incineration/disposal 5 % incineration/energy recovery. 21.2 m tonnes untreated, non-recovered	• Agriculture • Energy sector • Chemical sector • Pharmaceutical industry	€100-425 million per year (2013-2020) net benefits would result from the introduction of compulsory separated collection and biological treatment.
Critical Raw Materials	Waste Electrical and Electronic Equipment (WEEE)	9.5 Mt	3.3 Mt (35 %) collected for treatment	• Electronics Manufacturing	The market potential is up to €2.1 billion based on current levels of WEEE, increasing to €3.7 billion in future
	Aluminium	-	Current recycling rates: >90% in construction and automotive >60% from food packaging Volumes for recovery unclear, probably low	• Beverage industry • Food packaging • Metal production	Scrap aluminium would potentially represent an additional market of around €50-€150 m per year.

CE package priority sector	Waste stream	Volume waste stream	Waste treatment	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
	Solar panels	-	Current volumes for recycling and recovery very low	• Glass foam industry • Glass insulation industry • Industrial production	The current market potential is estimated to be low, at only €0.5 million per year, but expected to grow substantially.
Construction and Demolition Waste (C&DW)	Concrete, Bricks, Tiles, Ceramics, Roofing, Insulation, Wood, Carpets, Plastic pipes, Organics(e.g. prunings, Trimmings, branches), Metals, Gypsum, Glass, Hazardous waste, Miscellaneous.	297 Mt	94 % was treated. Of treated waste: 88 % recovered 12 % landfill/disposal 0 % incineration/disposal 1 % incineration/energy recovery. 51.3 m tonnes untreated, non-recovered	• Construction • Manufacture of clay building materials • Agriculture • Infrastructure – roads	Current market €0.8 billion/year. If recycling potential can be increased to 75 % of produced, the market would be €1.4 billion per year.
Biomass & Bio-based Products	Clothing / textiles.	2.3 Mt	81 % was treated. Of treated waste: 83 % recovered 8 % landfill/disposal 1 % incineration/disposal 8 % incineration/energy recovery. 0.76 m tonnes exist untreated, non-recovered	• Plastics sector • Construction • Textile industry • Automotive industry • Agriculture • Energy recovery • Rubber industry • Energy industry • Civil engineering	An estimated market potential of up to €270 m.
	Natural rubber, primarily from used tyres.	3.3 Mt	80 % was treated. Of treated waste: 45 % recovered 1 % landfill/disposal 1 % incineration/disposal 45 % incineration/energy recovery. 1.9 m tonnes untreated, non-recovered		Currently, the maximum market potential is of around €115 m.

CE package priority sector	Waste stream	Volume waste stream	Waste treatment	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
	Wood	50.3 Mt	87% was treated. Of treated waste: 46% recovered 1% landfill/disposal 1% incineration/disposal 52% incineration/energy recovery. 30.1 m tonnes untreated, non-recovered		The market potential could be worth between minus €600 and €2700 million per year.
	Used oils Including: Vegetable oils	4.2 Mt	56 % was treated. Of treated waste: 86 % recovered 1 % landfill/disposal 4 % incineration/disposal 10 % incineration/energy recovery 2.2 m tonnes untreated, non-recovered	• Energy recovery • Chemical industry	Used cooking oil fuel a market worth up to €1.6 billion.
Other	Metals	21.4 Mt (slag)		• Cement industry • Glass industry • Foundry industry • Petrochemical industry	Not re-used slag estimated €140 million/year
	Batteries – automotive batteries, industrial batteries and portable batteries[27]	1.7 Mt	88% was treated. Of treated waste: 97% recovered 3% landfill/disposal 0% incineration/disposal 0% incineration/energy recovery	• Steel industry • Construction industry • Battery producers	Market values for recovered batteries are unclear.

[27] Distinguished in the Batteries Directive 2006/66/EC

5.5. Market potential: landfill diversion opportunities

5.5.1.Introduction

Following the framework presented in section 5.3, an estimation of market potential for industrial symbiosis in Europe is produced based on **cost-avoidance savings from landfill diversion**. This approach focuses on potential cost savings (linked to avoided costs of landfilling) to industry from the adoption of industrial symbiosis and other approaches (i.e. circular economy and conventional recycling). For the calculation, we have considered market potential for industrial symbiosis based on landfill diversion due to increased recycling (the analysis does not consider energy recovery solutions within IS scope). The main **assumptions** for the analysis are the following:

Through IS (and other approaches) it is possible to reduce landfill, as the case studies that we have reviewed have consistently shown.

The analysis is based on a scenario where each country manages to catch up with the best performing countries in terms of recycling for each waste stream.

It is not possible to distinguish potential from IS approaches and other more conventional approaches to recycling, but the analysis aims to analyse whether there is an untapped potential as a whole, and therefore also for IS.

As stated before, estimation of cost savings also need to be treated as absolute maximums. The calculation does not account for the costs associated with recycling or reutilising the waste streams.

On the other hand, it is also important to note that estimations focused solely on cost avoidance opportunities associated with industrial symbiosis and, therefore, the values do not include potential benefits associated with prevention of resources becoming a waste and further uptake of the concepts of 'by-product' and 'End of Waste criteria' as well as the opportunities generated by the adoption of more optimal solutions that maintain the value of the resource (moving waste up the waste hierarchy) or the business opportunities associated with new uses of previously discarded resources.

5.5.2.Main assumptions

For this part of the market analysis, the assessment relies on three main premises: 1) through IS and other approaches (which also include conventional recycling), it is possible to assume substantial waste diversion from landfill. This is consistent with the findings of the mapping exercise and review of case studies; 2) we have assumed all countries increase recycling rates to the level of the best performers. This rests on the simplifying assumption that the waste streams are fundamentally homogeneous across countries within waste categories and that diffusion of best available technologies (BAT) and waste logistics is homogenous across countries. The analysis thus does not consider transaction, learning and infrastructural costs associated with landfill diversion opportunities; 3) the analysis assigns all potential gains from landfill diversion to IS practices when, in reality, this would be a combination of conventional recycling, changes to production processes and IS.

Diversion from landfill potentially entails a range of positive benefits including: 1) CO2 emission reductions; 2) increases in resource efficiency; 3) generation of value associated with development of secondary markets. The scope of this study, however, concentrates on the quantification of economic benefits to industry and does not account for other societal benefits.

Future analysis needs to better understand variations in composition of waste stream within waste categories and how this affects potential recyclability. There is also insifficient understanding of key incentives and outlets for waste utilisation (excluding incineration) across MS. Also the role of technologies, policies and infrastructures for specific waste streams, excluding municipal solid waste, needs to be further investigated.

We should also note that more widespread application of the concept of 'by-product' and application of 'EoW criteria' means that a substantial potential for IS may not be reflected in this market analysis. In this respect, one should note that implementation of these legal concepts has differed substantially across MS. Data is not available in most cases and quantification of potential is, thus, extremely difficult.

Harmonised approaches for data collection and reporting to the EU will significantly improve the foundations of more accurate calculations of market potential for IS. Reporting of volume and type of resources transacted as by-products as well as transaction of resources which achieved 'End of Waste' status will contribute to identify main areas of opportunities and market size.

The role of policies although fundamentally influencing the analysis, is only considered with regard to landfill taxes shaping total landfill costs, further considerations will be analysed in more detail in section 8. For example, changes in landfill tax could significantly increase the cost-saving opportunities of IS and thus increase the likelihood of companies engaging in mutually rewarding transactions. However, the causality here is far from linear as business decision-making is also shaped by other relevant factors such as awareness of IS potential, risk perception, knowledge/technical resources and know-how and complementary policy instruments (e.g. landfill and incineration bans).

This analysis would also benefit from a much more in-depth understanding of characteristics, management practices and IS/recycling opportunities associated with each waste stream in each MS. This is far out of the scope of this study, but some examples of areas of opportunities have been highlighted in the previous section.

Also, better understanding of the framework of incentives of best performing countries is necessary. Several elements may shape the behavior of best performers. It may be connected to more homogeneous waste streams (and less contamination), which may also link to segregation and collection practices. It may also be associated with the existence of better developed secondary markets and demand for that waste stream in the country given its production fabric. It may also arise from a combination of policies that promote higher recycling or the existence of adequate technology for clean-up and recycling.

Inversely, differences between best and worst performing countries therefore could be explained by a combination of factors including: lack of well-developed secondary markets, lack of recycling/recovering technologies, substandard collection systems or inadequate framework conditions.

The calculation of market potential in this study is static: it does not consider changes/improvement to recycling rates by best performing countries over time, nor does it take into account the impact of changes to landfill costs over time, due to data limitations.

Details of the method of calculation are provided below:

Based on three best performing countries, we calculate the 'highest achieved recycling proportion' for each waste stream,

for each country, we obtain the difference between the highest recycling proportion for each waste stream across countries and the actual recycling proportion value in the country,

we convert the difference in proportion into difference in tonnage, estimating the amount of waste that could be diverted in tonnes,

we subtract the difference in tons from the landfilled tons for each waste stream to obtain 'potentially divertable landfill',

if potentially divertable landfill is smaller than landfilled tons (where landfill plays a more prominent role than energy recovery as waste destination excluding recycling), we proceed with potentially divertable landfill to obtain saved landfill tons, if potentially divertable landfill is bigger than landfilled tons (where energy recovery and incineration plays a more prominent role than recycling as waste destination excluding recycling), we proceed with landfilled tons to obtain saved landfill tons,

we multiply the 'landfill tonnes with saving potential' by the 'total cost of landfill' for each MS to obtain potential savings in landfilling costs by country

we sum up cost savings across MS for each waste stream to obtain the overall 'IS market potential based on landfill cost avoidance' for the EU28.

Further details of the calculation, data sources and examples are included in Appendix C.

5.5.3. Analysis of IS market potential from landfill diversion opportunities

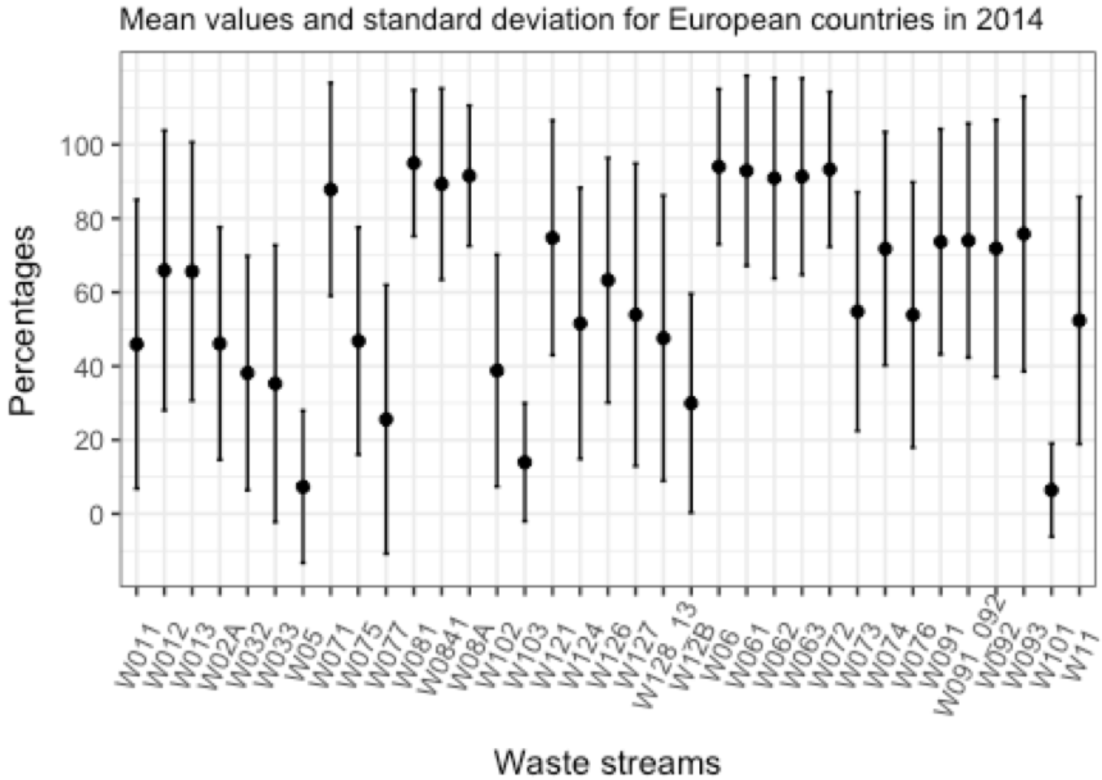
5.5.3.1. Waste destination by waste stream

The first step is to calculate current destinations of different type of waste streams. The main source of information is the "Treatment of waste by waste category, hazardousness and waste operations" in the Eurostat database [env_wastrt]. Based on the data, it is possible to calculate the mean values and standard deviations for recycling percentages of all types of waste per MS as well as the percentage of waste currently being landfilled by waste type. This step is necessary to identify the best performing benchmark countries by waste category. In the context of this study, 'best performing' refers to those countries that achieve higher percentages of landfill diversion and recycling by waste stream. Higher performing countries help to define what is technically achievable by type of waste stream under current state of the art technologies and manamagement approaches and therefore it provides an indication of the potential for IS (e.g. opportunities to divert waste from landfill and move waste up the waste hierarchy). Details of the calculations are provided in Appendix B.

5.5.3.2. Recycling potential

In Figure 16 we present the mean values and standard deviations of the recycling percentages per waste stream across the countries. The data reflects that there is considerable variation in recycling percentages across countries for different types of waste streams. This suggests that there is untapped potential for IS and other conventional recycling solutions.

Figure 16 Mean recycling percentages and standard deviation by waste streams (classified according waste codes)



Source: authors' calculations based on Eurostat

5.5.3.3.Relate landfill costs to waste streams

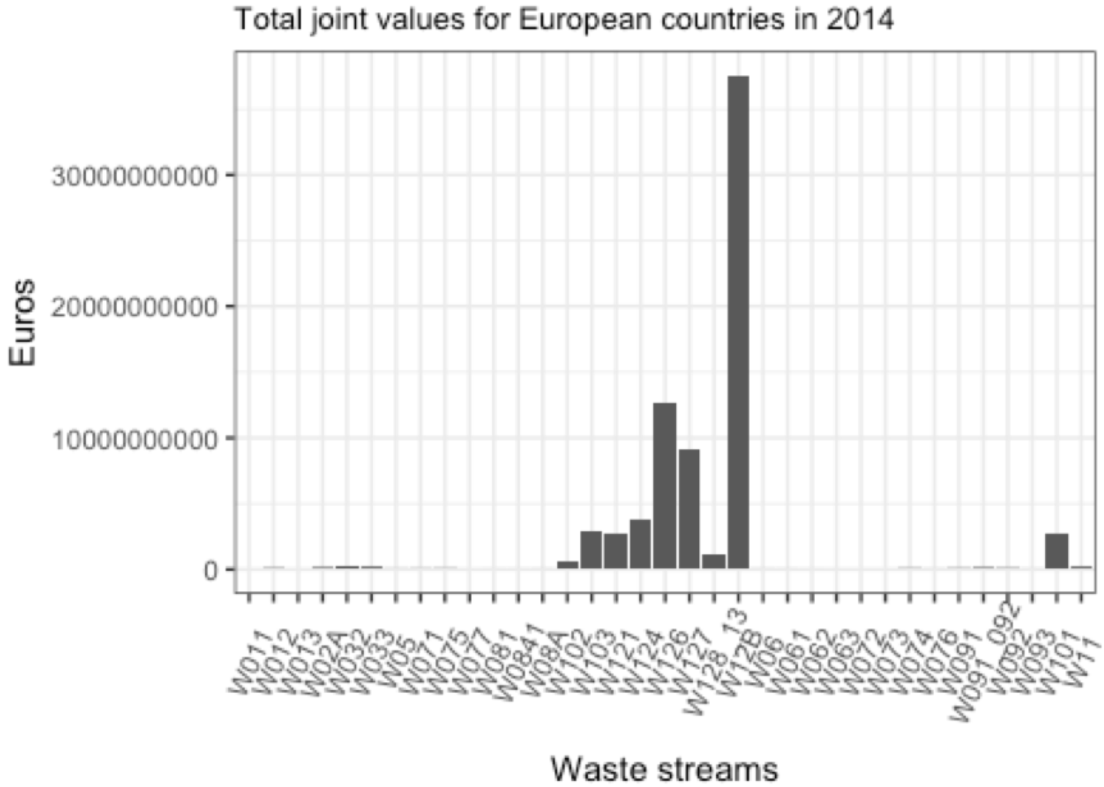
In order to understand cost saving potential from landfill diversion, the next step in the analysis consists of the calculation of the average landfill costs associated with different waste streams by MS. This draws upon the analysis of landfill costs made by Biointelligence for the European Environmental Agency (EEA, 2013). The calculation is based on the 'total typical charge for landfill' by MS and we merge it with the landfill data calculated by waste stream. It should be noted that the Biointelligence database is based on average landfill costs of household/municipal waste and, therefore, there may be substantial differences in the costs associated with different types of industrial waste. This is especially relevant for construction and demolition waste, which accounts for the waste stream by weight and, in some MS, is subjected to a differentiated lower tax (e.g. UK).

Future research needs to account for price differential of landfilling of different waste streams in MS.

By looking at the landfill costs, we can seek to identify where – on a purely cost basis - the market potential for diversion from landfilling would be highest. For this we combine the values of "Total typical charge for landfill (euros per tonne)" with the volumes of waste landfilled by waste stream to estimate the costs associated with landfilling different types of waste in each MS. In some cases, for some MS, this implies merging databases to obtain results by country. For example, we do that for BE-Fl (Flanders) and BE-Wal (Wallonia) and assign it to BE (Belgium).

Country by country, we have calculated landfill costs associated with different waste streams. The next step is to aggregate the by-country estimation into a EU aggregated figure, that shows estimated total landfill costs for each waste stream in EU28. This step provides an overview of which types of waste show more potential landfill diversion, from a purely economic point of view. Figure 17 shows the total landfill costs for different waste streams.

Figure 17 Total landfill costs for different waste streams



Source : authors' calculations based on Eurostat

To avoid double counting, all subtotal groups are excluded from the calculation . According to the analysis, biggest potentials are in W12B ("Other mineral wastes (W122+W123+W125)"), W126 ("Soils"), W127 ("Dredging spoils"), W124 ("Combustion wastes"), E121 ("Mineral waste from construction and demolition"), W103 ("Sorting residues"), and W101 ("Household and similar wastes"). This is not surprising, as these categories include construction and demolition waste and household waste where larger volumes of waste are generated. As mentioned in the methodological note on the limitations of this calculation, total landfill costs calculated are most probably an overestimation, as here we use average landfill cost without considering differential tax for C&D waste and inert/mineral waste which operates in some countries (e.g. the UK).

5.5.4.Best performing benchmarks for recycling

The analysis then seeks to identify best performers in terms of achieving higher rates of recycling for each of the waste streams. To calculate the benchmarks, the study uses the average of the three highest recycling rates by waste stream. Detailed results for each waste stream are provided in appendix C. The findings indicate that in many instances it is possible to achieve recycling rates close to 100 %. For example, in the case of W013 which refers to Used Oils, three best performers achieve percentages close to 100 % of recycling:

Table 11 Best performing MS for waste stream W013 Used Oils

Country	Waste streeam	Recycling percentage
BG	W013	1.0000000
LU	W013	1.0000000
PT	W013	0.9993020

Source: own calculations based on Eurostat, 2017

5.5.5. *Market analysis based on landfill costs avoided*

Building on the previous analysis, the next step is to identify the market potential for IS based on industry taking action to avoid landfill costs. Savings potential will differ from country to country depending on: 1) the relative importance of each waste stream; 2) the regulatory framework defining not only landfill taxes and landfill gate fee but also landfill bans and promotion of reuse and reutilisation and 3) the existing recycling infrastructure. Divergence in calculation methods for waste streams across MS may also bias the results.

To illustrate the calculations, waste W012 in the UK may be used as an example. Table Table 12 indicates the current destination of W012 acid, alkaline or saline waste.

Table 12 Waste destination for W012 in UK

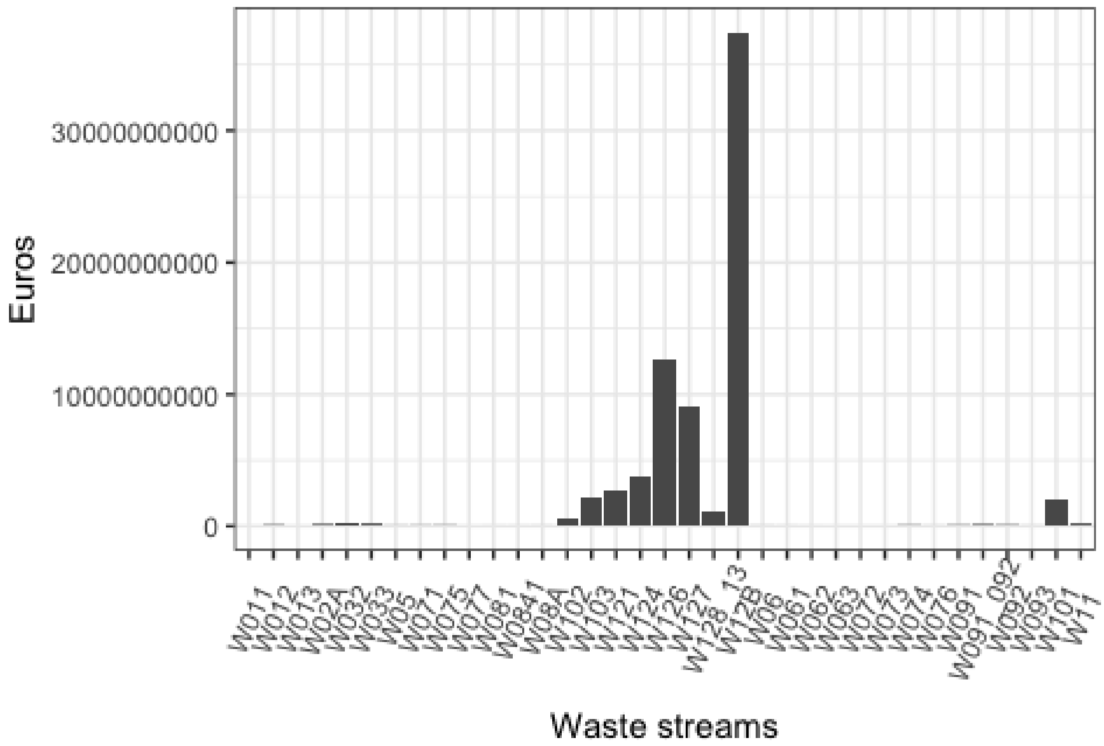
wst_oper	Waste	geo	values	TRT	Proportion_of_waste_stream
DSP_L	W012	UK	36543	133009	0.2747408
INC	W012	UK	0	133009	0.0000000
RCV_E	W012	UK	0	133009	0.0000000
RCV_NE	W012	UK	96466	133009	0.7252592
TRT	W012	UK	133009	133009	NA

Source: own calculations based on Eurostat 2017

To obtain the potential savings, the analysis compares the actual recycling proportion value (Proportion_of_waste_stream) between the UK and the highest recycling proportion (hwtp_prop) across countries for W012 and obtains the difference. In the case of the UK for W012 the difference is 0.274, which is the difference between current recycling 0.7252 and the benchmark (which is 100 % recycling in this case). Therefore, to catch up with the best performing country the UK would need to recycle an additional 0.274 of the waste stream. To translate the potential saving into economic savings, the rate needs to be converted to tonnes and then multiplied by average landfill costs in the UK, providing an estimation of potential economic savings linked to landfill diversion. The analysis also controls for other waste destinations, so that if for example a certain amount of waste stream W012 would go to incineration, the actual maximum available volume which could be divertable from landfill cannot be greater than actual waste landfilled.

Figure 18 provides an overview of potential savings by waste stream in Europe, if best performing recycling benchmarks were to be achieved across Europe and across waste streams.

Figure 18 Potential savings for each waste stream across countries



Source: authors' calculations based on Eurostat

In Figure 18 we can see that waste stream W12B ("Other mineral wastes") has the greatest potential in terms of monetary gains from landfill diversion, if all countries managed to catch up with the best performers in terms of recycling. Figure 18 necessarily correlates to Figure 17: as total landfill costs for different waste streams equal in many cases savings potential, given that in many cases benchmarks are close to 100 % recycling and, therefore, it seems plausible to achieve close to 100 % diversion from landfill. There are some exceptions to this, which are W103 (0.67), W101 (0.64), and W05 (0.57), waste streams which may include waste types that due to their characteristics (e.g. hazardousness or contamination) are not technically feasible or environmentally suitable for recycling. W103 ('waste from physical and chemical processing of metalliferous metals') is also among the few notable differences between Figure 17 and Figure 18.

To simplify the number of categories, it is also possible to group waste streams by main groups:

W12-13 ("Mineral and solidified wastes (subtotal)"),

W01-05 ("Chemical and medical wastes (subtotal)"),

W09 ("Animal and vegetal wastes (subtotal, W091+W092+W093)"),

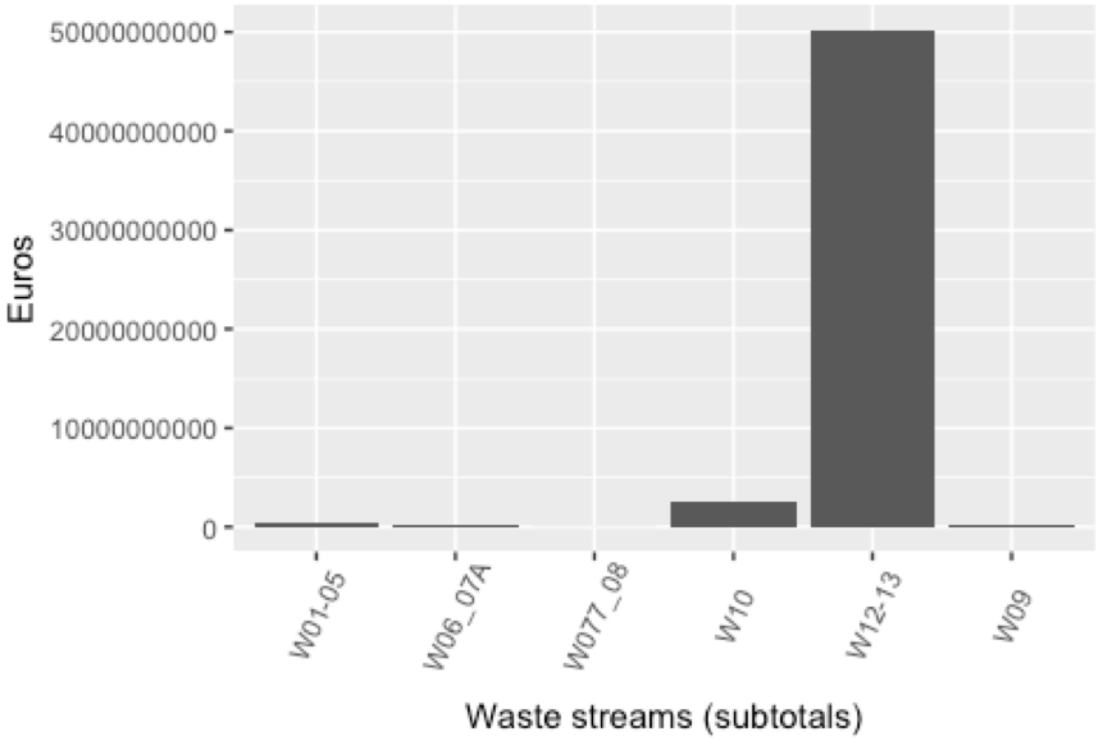
W10 ("Mixed ordinary wastes (subtotal, W101+W102+W103)"),

W06_07A ("Recyclable wastes (subtotal, W06+W07 except W077)"), and

W077_08 ("Equipment (subtotal, W077+W08A+W081+W0841)")".

Figure 19 summarises *potential savings for each waste stream across all countries* (sfewsac) for group categories.

Figure 19 Potential savings for each waste stream across countries for group categories



Source : authors' calculations based on Eurostat

Results show **that waste category group W12-13 ("Mineral and solidified wastes") has the greatest potential in terms of monetary gains from landfill diversion**, if all countries managed to catch up with the best performers in terms of recycling.

Finally, to come up with an overall figure of market potential for IS in Europe, the next step is to aggregate potential savings across all waste categories (details of the calculation is provided in Appendix C) and all countries.

5.5.6. Aggregated market potential for IS based on landfill cost avoidance

Finally, aggregation of potential by all waste streams and MS results in a market potential of **almost €73 billion**, which could be saved by industry if all countries across the EU28 caught up with the recycling rates of the best performers for the different waste streams, and thus managed to significantly divert waste streams from landfill through IS or other recycling practices. This figure calculates potential based on landfill costs avoidance only and, thus, additional benefits may be expected in terms of reduced costs of sourcing raw materials and innovation spill-overs. To this, societal benefits should be added linked to savings in CO_2, reduction of environmental costs of landfilling and potential creation of jobs. As noted above, however, this should be regarded as an absolute maximum and thus the aggregated potential is likely to be less, as costs associated with recycling alternatives have not been considered and landfill costs are based on average landfill costs for municipal solid waste (EEA, 2012) rather than the actual cost associated with specific waste streams. Most of the bias could come from C&D waste subjected to a lower rate in some countries and other mineral waste subject to special tax regimes and landfill gate fees.

The analysis would benefit from further research regarding additional economic and social benefits associated with IS initiatives from a life cyle perspective.

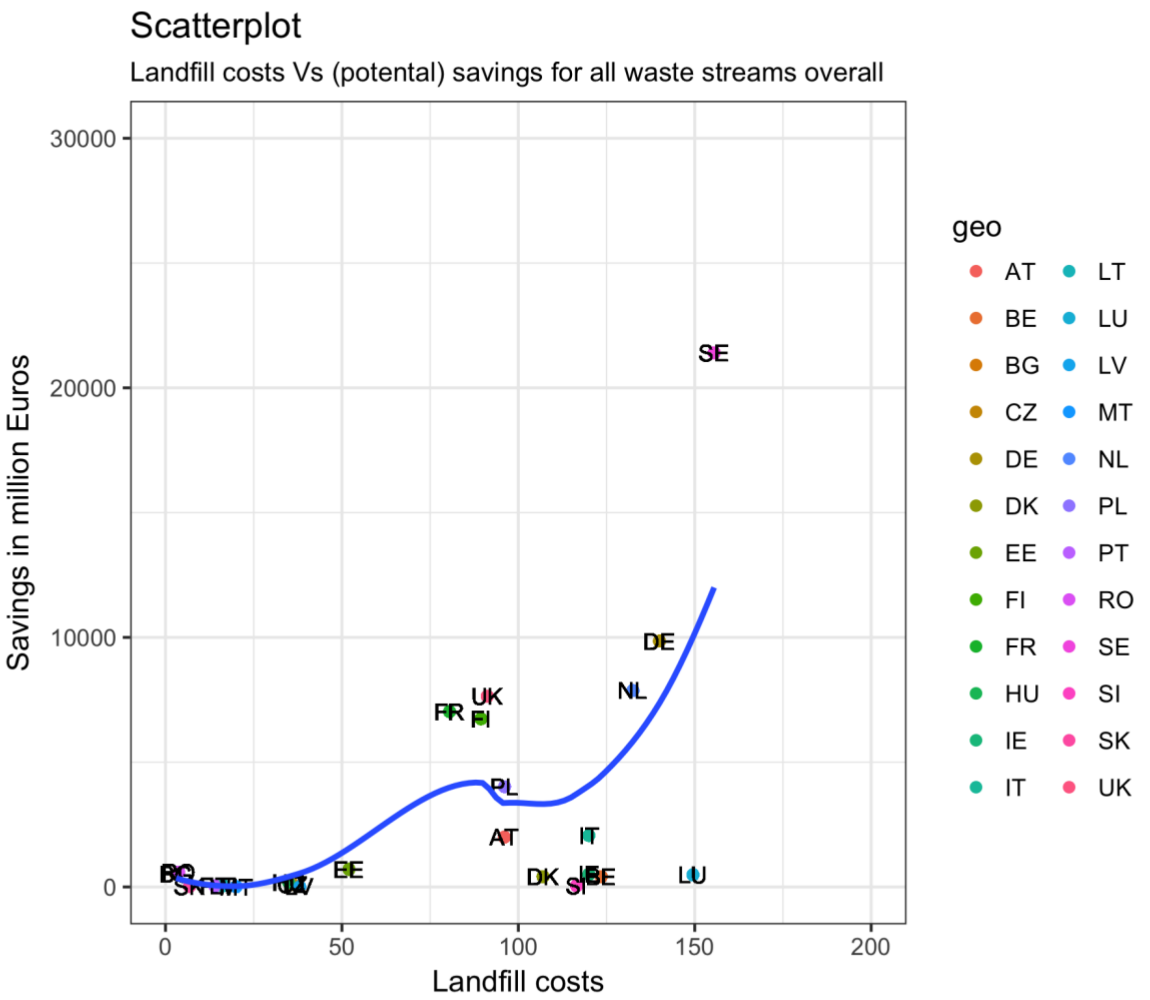
5.5.7. Analysis of individual potential for countries

The analysis also offers interesting insights if we explore potential savings of individual countries. Appendix C offers some details on the calculation for a small sample of countries (UK, IE) for each waste stream.

In future research, this analysis can be reproduced for all EU28 countries for which there is data, providing insights on specific waste streams with potential for landfill diversion and opportunities to adopt best practices from best performers.

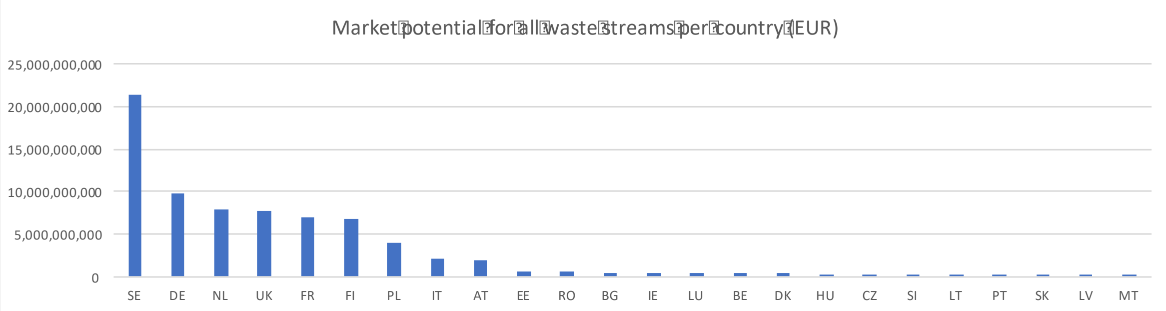
Table 13 shows aggregated market potential by MS for all waste streams. As one would expect, the market analysis highlights that highest potential correspond not to countries with a larger percentage of landfilling, but rather those that: 1) produce a higher absolute volume of waste (larger countries or those with an important extractive sector); 2) have higher costs associated with landfilling, including gate fees and landfill taxes. Taking this into account, it is not surprising that MS such as Sweden, Germany, the Netherlands and the UK, with high landfill costs combined in some cases with high absolute volumes of waste landfilled, are among those with highest market potential for IS (see Figure 20). These results seem to also align with the mapping of initiatives, showing some relation between development of IS activity, mostly self-organised but also facilitated, and greater market potential for IS activity.

Figure 20 Landfill costs vs (potential) savings for all waste streams



The following table provides detail on market potential *for all waste streams per countries* (sfawspc), based on landfill diversion cost avoidance.

Table 13 Market potential for all waste streams per country

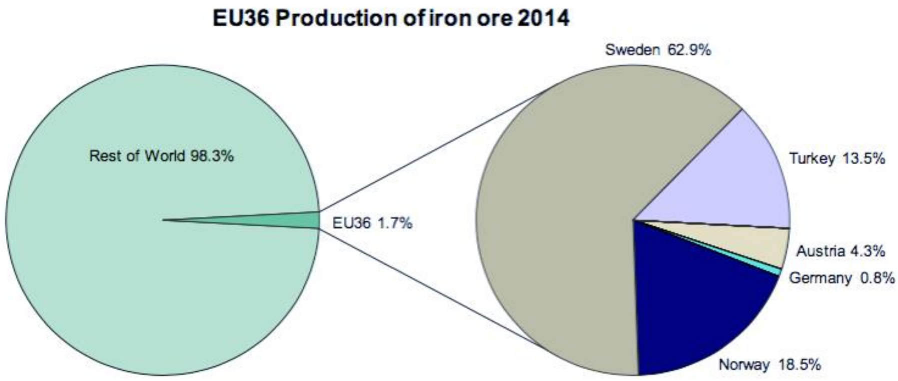


geo	Market potential for all waste streams per country (EUR)
SE	21,404,272,742
DE	9,851,936,998
NL	7,868,127,322
UK	7,642,871,207
FR	7,027,075,139
FI	6,738,395,705
PL	4,019,595,229
IT	2,062,826,951
AT	1,995,839,880
EE	706,952,005
RO	598,132,935
BG	513,762,687
IE	506,444,671
LU	488,037,955
BE	432,915,613
DK	412,841,631
HU	167,418,399
CZ	107,545,704
SI	49,428,499
LT	46,728,370
PT	39,720,745
SK	24,113,725
LV	13,963,110
MT	7,695,110

Source: own calculation based on Eurostat data and Biointelligence (2013)

Sweden is an interesting case. For a relatively small and environmentally progressive country such as Sweden, it is remarkable that *the savings for all waste stream per countries* (sfawspc) is so much higher than other bigger countries such as Germany, which has a similar magnitude of landfill costs. A closer look however reveals important differences. Although percentages of landfilling for a number of waste streams, such as municipal solid waste (MSW), are relatively small in Sweden, due to restrictive policies such as landfill bans, incineration bans, high landfill fees, mandatory recycling targets and Extended Producer Responsibility schemes, Sweden has a large minerals sector and it stands in the third place by volume of waste landfilled followed only by Bulgaria and Romania. This is due to Sweden being a major mining country and, in particular, an important iron ore producer. The following graph shows Sweden's share of global iron production.

Figure 21 Sweden's share of global iron production



Source: British Geological Survey 2016, 241

Once one excludes major mineral wastes, this figure would be substantially lower as Sweden is indeed a high performing country in terms of recycling for a number of waste streams.

5.6. Is there correlation between landfill costs and landfill diversion?

A key question that arises from the analysis is whether higher landfill costs are driving landfill diversion. Anedoctal evidence may seem to support this. The study by BIO IS (2012) also seem to suggest correlation between landfilling costs and rate of landfilling of MSW, however further investigation of the data is required to understand to what extent this claim is supported by evidence.

In this research, a basic correlation analysis has been performed to try to understand whether and to what extent landfill costs may explain recycling rates. Appendix D contains detailed description of correlation values by waste streams.

The analysis suggests significant positive moderate correlations between landfill costs and recycling of:

- animal and mixed food waste,
- vegetal wastes,
- animal faeces, urine and manure, and
- combustion wastes

For most of the other waste streams the analysis suggests positive but not significant correlations, with some exceptions such as spent solvents for which significant negative moderate correlations were found.

This indicates that landfill costs may drive recycling of different types of waste.

The analysis has also looked at the correlation between landfill costs and landfilling for the different waste streams. Similarly, in this case, the analysis points to a strong negative correlation between landfilling costs and the landfilling of household and similar wastes, and a moderately strong negative correlation between landfilling costs and the landfilling of paper and cardboard wastes. Also, moderate but significant negative correlations between landfilling costs and the landfilling are found for:

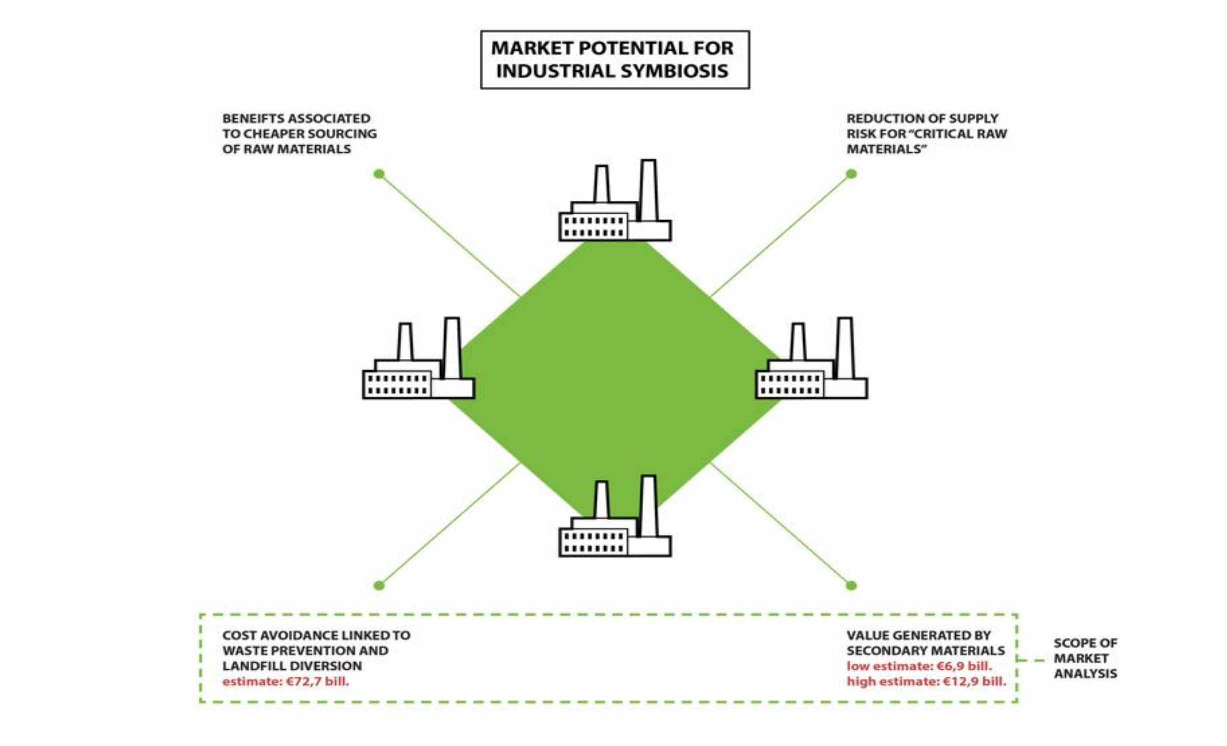
- mixed and undifferentiated materials,
- animal faeces, urine and manure,
- vegetal wastes,
- common sludges,
- chemical wastes,
- combustion wastes, and
- rubber wastes.

Results from the correlation analysis thus suggest that increasing landfill costs, associated perhaps with other instruments such as landfill bans and incineration bans, may drive landfill diversion and higher recycling. This is consistent with the results of the mapping, analysis of case studies and stakeholder consultation that highlighted the landfill taxes as important instruments to drive the adoption of industrial symbiosis approaches.

5.7. Summary analysis of market potential

Merging both approaches provides some idea of the market size potential. By looking at the positive value associated with priority waste streams and the cost-avoidance potential of IS activity, it can be concluded that there is a substantial market potential for IS. Moreover, both approximations of market potential are complementary, as landfill diversion could bring cost savings that would add to the value extracted from secondary materials. Figure 22 below summarises market potential from both perspectives.

Figure 22 Market potential for Industrial Symbiosis



Source: authors

What are the key waste streams with more potential

Taken together it is clear that there are significant unused waste streams in the EU for which other applications are clearly identified. The volumes of these waste streams, and market characteristics as currently understood, suggest at first approximation, market potential across the sectors in the EU running into hundreds of millions of euros per year and potentially billions of euros, especially in the areas of waste electrical and electronic equipment (WEEE), construction and demolition waste and plastics. From the point of view of cost-avoidance and given its volume, there is also considerable potential for diversion of mineral wastes, construction minerals and others streams of C&D waste.

A number of areas, for which potential is currently low but are expected to grow exponentially in the future, include recycling of critical raw materials (included in WEEE), batteries and solar panels (and other renewable technologies). Recycling of this could have a significant value due to scarce and critical materials contained in them. However, volumes that will make this attractive will only become available in around 10 years, although some cutting edge facilitaties have been developed in Europe to treat these waste streams with potential.

What needs to happen for the potential to be achieved

Much of this potential remains untapped as the necessary incentives to build a business case, the technical knowledge, equipment and the physical infrastructure are each lacking to varying extents. The analyses have also shown that creating market potential for IS also fundamentally depends on setting adequate framework conditions. Cost of landfilling is a crucial element in defining IS potential from the cost-avoidance point of view and thus to create incentives for the private sector to engage in IS. The analysis of the correlation between landfilling costs and recycling and landfilling also seems to point to this direction. There are also a host of practical socio-technological issues, that range from the collection and segregation to the safety, quality and trustworthiness of secondary raw material waste streams, that need addressing. It is clear that these already play a role in the volumes of waste that are treated and recovered and the costs and prices achieved for such waste streams.

Is part of this value captured by current recycling? If so what is the value added of IS ?

Waste treatment statistics show that treatment and recovery rates for waste materials are in many cases already quite high and generally increasing. There are, however, important divergences between MS in terms of the percentage of waste recovered and opportunities to move waste up the waste hierarchy. This is precisely the area where IS can play a strategic role. The main aim of IS is not just diverting waste from landfill but maximising reutilisation and valorisation of those waste streams and preventing resources from becoming waste in the first case. In this analysis of market potential, we have concentrated on the residual economic value of waste resources, due to data limitations. The analysis suggests that, while recycling has increased substantially, there are still large untapped opportunities to extract more value out of waste products and find better outlets for secondary materials. IS can play a crucial role in enabling this and introducing innovative solutions for complex waste streams, where current recycling pathways are suboptimal.

The analysis has also shown that there are high volumes of material that may be available for IS including for certain materials such as textiles, wood waste, C&DW, plastics and used oil, with substantial potential for IS. A preliminary review of practices, points to well-developed solutions to prevent these resources from becoming waste, either through direct reuse or through valorisation activities. IS approaches can also complement circular economy strategies to identify business opportunities from underutilised resources, by providing a systematic approach to the analysis of resource flows in an area or in the economy and offering practical pathways to implement the closed-loop systems included under CE approaches. This, combined with a focus on designing out waste and improving design of products and services, may have transformational implications for European production systems.

Market potential is only one of multiple benefits of IS, other indicators are also important

The market potential estimations in some cases also include estimations of other benefits such as cost savings, fiscal gains or environmental benefits that are not necessarily interesting for market players but are interesting for society as a whole. The monitoring and evaluation of industrial symbiosis normally closely considers these other types of indicators in addition to the market potential, taking a more holistic view of benefits which combine economic, environmental and social benefits. Yet the challenge remains to provide a business case based only on private costs and benefits that can drive sustainable IS models, and this has been the scope of this study. The mapping section provides case-based estimation of benefits associated with IS initiatives that include reduction of waste; reduction of consumption of primary raw materials; savings in GHG emissions and job creation.

How do these findings relate to findings from previous studies

The findings are consistent with those from other studies on the potential volumes, focus sectors and complexities involved. In terms of value there were only limited estimates from existing studies and those are consistent with the types of values presented here.

6. BARRIERS AND DRIVERS FOR IS

6.1. Market and system failures in IS

The review of case studies and best practices demonstrates that IS networks with the potential to generate environmental and economic benefits already exist in Europe. However, the potential to scale up these networks is faced with a number of constraints explained by the market failures preventing the scale up. Without state interventons, via removal of regulatory barriers, promotion of secondary markets or IS facilitating programmes, existing market conditions, on their own, may not be sufficient to encourage IS projects to become viable and economically attractive for companies, especially as prices of primary raw materials remain low. At the same time, the literature stresses that economic/market factors alone are insufficient to explain the success or failure of IS networks (e.g. Domenech and Davies, 2011; Mazzucato, 2016). Economic drivers also do not fully explain the transition from simple, straightforward IS transactions to more complex exchanges, that require further business-to-business collaboration. Mazzucato (2016) argues for a shift from market failures thinking towards a more encompassing analysis framework for the role of the state as market shaper and creator, transforming the markets by providing directions of change, e.g. through green growth[28].

In the analysis of IS it is helpful to have a systems perspective on the viability of the synergies. The systems approach, borrowed from innovation system discourse[29] can cover the following elements defining economically sustainable IS ventures:

- Network – organisations and intermediaries that engage in IS (as a partner or a node), whose interlinkages are based on cooperation and information and knowledge exchange.
- Capabilities – the skills, expertise, knowledge needed to perform or adapt to changes towards symbiotic actions. For successfull IS, network actors would need to have technical knowledge (e.g. how to make use of the secondary materials, how to assess their quality, what technological solutions to use, etc.), as well as soft skills (e.g. project management, negotiations, etc.)
- Infrastructure – usually these are technical infrastructures, technologies, logistical arrangements, ICT necessary for the handling of big data, providing potential technical solutions and tacit information in support of implementation of IS activities.
- Institutions – including formal instututions like regulatory frameworks or policy climate that create rules and settings make IS possible and viable.

These system failures in combination with the market failure could explain why industrial symbiosis may develop in one region, but may fail to do so in another region with a similar material basis (economic structure and mix of sectors). The table below presents systemic and market failures that can be seen in the case of IS.

Table 14 Market and system failures in IS

Failure	Main characteristics
Market failures	
Externalities	Enterprises are involved in transactions where they cannot achieve the expected profits

[28] Mazzucato, M., 2016: From market-fixing to market-creating: a new framework for innovation policy, in Industry and innovation, 2016, Vol 23, no 2, 140-156 http://dx.doi.org/10.1080/13662716.2016.1146124

[29] The Innovation systems discourse defines such a system as an interactive **network** of actors possessing a set of **capabilities** whose interaction result in innovative activities and based on knowledge exchange and supported by **infrastructres** and on formal and informal **insututional settings** (rules).

Information asymmetry	Failure to get right information e.g. on technologies, economic opportunities, prices, resources
Market power	Lack of competitiveness of the IS approach (e.g. waste management is still cheaper)
System failures	
Network	Failure to establish cooperation, linkages, information exchange due to distances
Capability	Inability of firms to adapt freely to structural changes, new technologies or new organisational concepts
Infrastructural	Lack of support facilities, technologies, logistical system needed to launch and maintain IS activities
Institutional	Lack of favourable regulatory framework conditions/regulatory, political barriers

Source: authors, based on EC (2009) Pro Inno Europe paper nr. 13

To analyse market and system failures faced by the IS ventures, in this study the IS facilitators have been consulted through the survey on the factors that drive companies to engage in IS and barriers preventing them from doing so. Results are analysed in the following sections.

6.2. Drivers for companies to engage in IS

The literature suggests that economic drivers are key in the emergence of IS processes (Desrochers, 2004; Chertow, 2007). The survey with IS facilitators performed within the framework of this study confirms this finding.[30] The **main incentive is the prospect of the decrease of company costs related to resources** such as raw materials, water or energy, reducing the waste generated by the company, as well as creating new areas of revenue, increasing company turnover, see Figure 23. It is clear that **companies only engage in such synergies when there is a clear economic gain.**

The stakeholder consultation discussions also point to the trend of resource scarcity as one of the key long-term motivations for companies to engage in IS. Key further drivers include increasing the competitiveness of the companies engaging in IS by offering alternative sources for raw materials or access to innovation, new clients or opportunities for collaboration.

In addition, the survey with IS facilitators also suggests that the **companies' own vision for the future** is also important in their choice to take part in IS networks and in the realisation of synergies. Companies with interest in building new partnerships, in accessing innovation, as well as the ones with an existing environmental policy, or in search for a more sustainable business model are among the ones that tend to engage in IS, based on IS facilitators' experience.

[30] The survey with IS facilitators relied on a strategic sampling technique, which rendered 22 complete answers. As a consequence, the survey results can be considered indicative and not representative of the entire population of IS facilitators in EU.

Figure 23 Perceived drivers for companies to engage in IS transactions and cooperation

Response	Total	%
Decrease company costs with resources (e.g. energy / raw materials / water etc.)	14	64%
Reduce the waste the company is generating	12	55%
Create new areas of revenue	11	50%
Increased turnover for the company	10	45%
Building new partnerships with other companies	10	45%
Help to achieve the environmental policy and targets of the company	9	41%
Changing the company's business model to a more sustainable one	8	36%
Help divert waste from landfill	7	32%
Access to innovation	6	27%
Acquiring new clients	6	27%
Improved quality/security of inputs	4	18%
Satisfaction of CSR requirements	4	18%
Create jobs	3	14%
Other, please specify	0	0%
Do not know	0	0%

Source: authors based on survey with IS facilitators; n=22; multiple-choice question

6.3. Barriers to IS synergies

There are a range of different factors affecting the realisation of synergies. They include: a) characteristics of the waste stream/resource (e.g. bulkiness) and its nature (e.g. heat and steam can be only transported over short distances); b) market value; c) transport costs; d) regulatory requirements associated to transport and treatment; e) innovation/research required to transform the 'waste' into a resource; f) storage and timings and g) lack of support/time/capability for the realisation process.

The literature has extensively reviewed success factors and barriers to IS development. Main findings are summarised in the table below. Facilitation approaches help to overcome some of the barriers to IS by increasing the knowledge of resource flow and potential synergies, reducing transaction costs, risk and uncertainty of IS transactions and promoting collaborative structures for scalability (Ashton, 2008). At the same time, industrial activities need to be complementary in their needs and resources (Lowe and Evans (1995); Pellenbarg (2002); Chertow (2007).

Table 15 Barriers for the realisation of synergies

BARRIERS	
Technological	Technological barriers may prevent IS to happen due to: a) the unavailability of technologies that allow the transformation or clean-up of the waste stream so that it can be used as a resource; b) insufficient knowledge and/or experience regarding the performance of specific waste streams when used as inputs and c) price of available technology does not guarantee the commercial viability of the synergy.
Economic	Even for technically feasible synergies, economic barriers may prevent their realisation based on: a) cost of the IS project in comparison to

	other forms of waste disposal or treatment and b) landfill costs. Currently, landfill costs in EU remain comparatively low and landfill is still a convenient and cost-effective solution (landfill cost has been growing in the past years and is expected to continue to do so in future).
Financial	Technical and economically viable synergies may also be prevented by adverse financial context with limitations in credit and policies of cost reduction may cut investments in projects with longer pay-back periods.
Geographical/ physical	The geographical and physical scope of IS projects is also limited by: a) technical viability of transporting certain type of resources over long distances (such as steam or heat); b) the cost/value ratio of the transportation, in case of high volume/low cost resources, such as sludge and c) the environmental rationality of transporting waste materials over long distances.
Regulatory	Although regulation has been a driver for some IS synergies, the classification of waste in regulation and the requirements defined for handling resources classified as waste may also in some cases prevent the realisation of synergies as it imposes extra requirements for the companies involved in the synergy, as the recipient needs to be a registered waste manager and the transportation has also to be undertaken by a registered waste transport company. This not only increases the cost of the project but also its complexity and thus extends the time required for the exchange to happen. This may discourage organisations in sectors such as construction, where contracts specify time of delivery.
Organisational/ cultural	Although not common, some companies may be reluctant to replace virgin raw materials by waste materials. Another important barrier is the lack of a clear understanding of waste costs in a company. Companies may have only a rough idea of their waste costs. Moreover, waste costs are generally identified with landfill and/or disposal costs, failing to capture the totality of cost associated with waste such as cost of waste resources and energy, cost of production and storage, among others.
Negotiation	A common reported cause of failure of technical and economically viable synergies is the inability of organisations to reach a mutually beneficial agreement. This is connected with both organisational and communicational barriers. Companies that have been paying for the disposal of their waste, if they perceive that another company may generate a commercial benefit, they may try to push the negotiation further by elevating their price/benefit expectations.
Communicational	Problems of communication between companies and disparity of business culture may also pose risks to the process of realisation of synergies
Risk and responsibility	Issues of risk and duty of care linked to the use of waste materials are also considered to negatively affect the realisation of IS synergies, especially those involving hazardous waste.

Source: (Domenech, 2010)

A crucial issue that may act as a barrier to IS is **the match of the timing** in which a waste is generated and the timing in which it may be needed (particularly in the construction sector). This is of key importance for some sectors dealing with large volumes for waste streams and very constrained timelines for the delivery of the projects/products; this is a barrier that affects the implementation of many of the opportunities in the construction sector; for an IS transaction to be successful, there should be some overlap between the timing in which a waste stream in one neighbouring site is produced and the timing in which it is required by another company/sector.

The most significant barriers highlighted in the survey and interviews are **the risk and uncertainty linked to IS synergies**, both in terms of potential cost-saving but also in terms of regulatory compliance; **lack of technical expertise to identify potential** (something that facilitators can help to overcome); lack of time and capability within the company, especially in the case of SMEs and costs associated with transport and storage (see below Figure 24 with findings from the survey). Results from the interviews and the survey also point to **informational barriers as barriers preventing IS transactions**. Companies may hold a good overall knowledge of the resources within the own value chain but little knowledge of resources and waste streams generated by other value streams

The 'other' barriers mentioned by survey respondents in the open answers generally refer to regulatory barriers, which will be discussed in a different section of this report. Another respondent mentioned that "symbiosis can only become successful in the case of an objective, government-supported broker is involved". This conclusion was confirmed in the focus groups and interviews with various IS facilitators and industry associations.

Figure 24 Barriers to IS transactions – results from survey with IS facilitators

Response	Total	% of responses	%
Risk and uncertainty linked to difficulty to identify costs-benefits and return on investment ex-ante	14		64%
Lack of time	12		55%
Logistics: high transport costs and dispersed production sites	9		41%
Other, please specify	8		36%
Too high costs of the needs for the changes in procedures or processes implied by IS transactions.	8		36%
Lack of technical capacity and expertise	8		36%
Not enough information	7		32%
Transactional costs (negotiation costs)	5		23%
Upfront costs for participating in IS networks or transactions (e.g. membership fees, pay-per service fees)	4		18%
Difficulty to assign benefits among parts, once the transaction has been successfully implemented	4		18%
Storage space	4		18%
Other organisational barriers [please specify]:	2		9%
Do not know	0		0%

Source : authors based on survey with IS facilitators, n=22; multiple-choice question.

The barriers faced by facilitators in engaging companies in IS networks and achieving performance are to a large extent related to the low market incentives for companies to engage in IS, given the unattractive economic value of waste and by-products (see Figure 25).

Disincentives for engaging in transactions also stem from the problems of **prices for raw materials** and **technological lock-ins** in the traditional waste management practices. Kemp et al. (2013) studied EU secondary markets for established materials and found that they are highly influenced by the dynamics of the primary materials markets. They also found that reuse, recovery and recycling routes may be subject to technological lock-ins that prevent in some cases adoption of more innovative solutions. Similar problems can be suspected in the area of industrial symbiosis, where more efficient solutions and IS synergies compete with traditional routes of waste recycling/disposal and are largely affected by the prices, as well as dynamics at primary markets. It has been pointed out during an interview, that traditional waste management industries can see IS systems as competing or threatening their business (by reducing the waste inputs to be handled)[31]. At the same time the waste management companies by doing recycling of waste tend to argue that facilitation

[31] Interview with Prof. Pack, EIP South Korea

activities needed for IS correspond to the role they are playing as waste recyclers and intermediaries between waste generator and purchaser of the recycled product.

Moreover, one further barrier identified for IS cooperation is related to the risks that come with cooperation along the value chain. Oftentimes, economic gains from IS arrangements only appear based on long-term cooperation with partners within the value chain, which diminish the flexibility of participating companies to react to market developments (EIB, 2015). An increased number of participants or alternative suppliers or buyers available in the same circular value chain could be a solution to this issue, however, the complexity of the coordination process would also increase, and would need a 'catalyst' to initiate or sustain the relationships (ibid). This can be considered another confirmation for the need for a facilitator of the symbiosis arrangements.

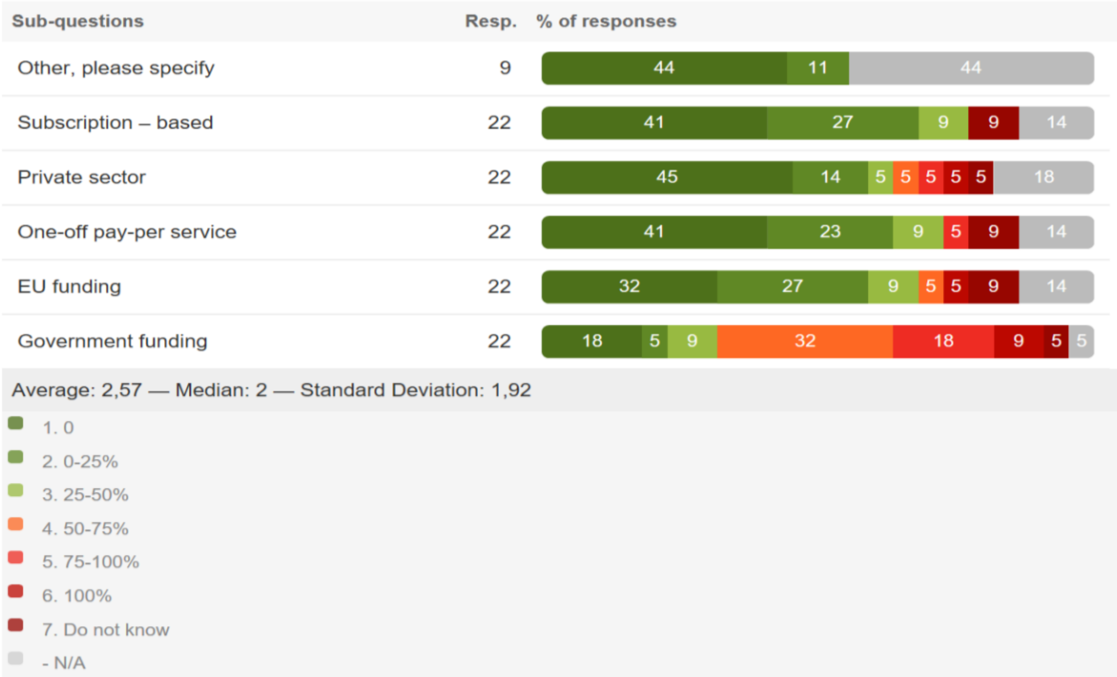
Figure 25 Barriers to facilitators of IS at network level

Source: authors based on survey with IS facilitators, n=22; multiple-choice question.

6.4. Challenges to economic viability of IS facilitation

The short-term funding for facilitators has been seen as another barrier to the performance of IS facilitation. **The majority of the networks identified in Europe are largely dependent on public sector funding and are not self-sustainable**. Based on the survey undertaken with IS facilitators, 59 % of the respondents depend on goverment funding for more than half of their budget: 32 % of them (7 out of 22) are depending on government funding for 50-75 % of their budget, while 18 % (4 organisations out of 22) for 75-100 % of their budget. Two organisations surveyed depend 100 % on public funds for their budgets. Very few of the respondents depend on subscription fees or the private sector to a large extent. The majority (65 %) of the respondent facilitators funded by public funds have a duration of funding planned for 1-3 years, while 5 % of them have secured funding for less than a year. This indicates the very unstable funding situation among the overwhelming majority of IS facilitators.

Figure 26 The funding structure of IS facilitators



Source: authors based on survey with IS facilitators; n=22; multiple-choice question.

During the interviews and survey, facilitators have stressed that some **IS projects have a low margin and high uncertainty** which makes it difficult to work merely on a commercial basis. Some of the programmes complement public income with private funding through a number of mechanisms including subscription fees or one-off / per service pay, but even in these cases this represents only a small share of their funding. Another key element suggested is that the nature of the funding is very short-term, sometimes renewed on a yearly basis (e.g. Northen Ireland or SMILE Ireland) or secured for a short period of 1-3 years. This also contributes to creating uncertainty about the future of the network, which may affect the feasibility of more challenging types of synergies that require more time to implement (and sometimes are associated with innovation). Similarly, programmes have experienced difficulty in recruiting the right quality of faciltators when the funding is short-term or uncertain.

Moreover, when asked to assess whether the programme could continue without public funding, the majority of IS facilitators (77 % of the 22 respondents) are convinced that the programme would not survive on private sources. Only 23 % believe it is possible to operate on private funding only. However, it is important to note that this result may need to be nuanced by the results of the interviews, which show that the majority of the facilitators answering the survey have been relying only on public funding, without attempts to commercialise the programme. In addition, some interviewees noted that there may be a need for a public-private partnership model to ensure sustainability as well as relevance of the IS initiative to local or regional economic and environmental development goals. Several interviewed facilitators also noted that significant results and commercial viability could rather potentially be reached after a longer-term public sector (co-)investment in the programme, as the implementation of IS synergies is a lengthy process.

The IS facilitators' reasons for not believing the programme can continue without the public funding can be split in two main categories: on the one hand, they are related to market failures and the **difficulties of finding a feasible business model for IS facilitation based on market principles only.** These include the low incentives for companies to pay for a facilitator's IS services or the low prices of competing raw materials:

- "Businesses do not always see investing in IS synergies as a priority, so receiving suport from [the facilitators] IS consultants helps in getting synergies over the line which otherwise may not happen. Once a synergy is created, both companies are independent of the facilitators' services, therefore they would not see the value of contributing financially yearly thereafter."

- "Many of the member companies are too small to pay substantial member fees."
- "We are in the starting years. Companies have to have time to understand the business potential because of the unprofitable top margin."
- "Environmental initiatives are only succesful with external support."
- "Companies can be interested in joining an IS membership if the benefit is clearly monitored and shown to them."

On the other hand, other reasons believed to be related to the participants' assumptions for an appropriate governance of IS facilitation. **Public-private cooperation in IS seems to be thought important for many IS facilitators**, in order to either launch the IS process (but not fund the implementation of synergies), or share risks and responsibility for the implementation process.

- "The [public] funding is meant to launch the process and private funding is aimed to handle the project in a sustainable way."
- The aim of the initiative is a shared responsibility of private and public sector; in case of 100 % funding this is out of scope.
- It is necesary to [have an] impulse [from] public initiatives in order to encourage all the actors (politicians, companies, public sector, councils...)"

6.5. System and market failures – assessment by stakeholders

The consultation with stakeholders has confirmed the existing knowledge about the barriers preventing companies from joining IS and provided deeper insights into system and market failures of IS models in the current conditions. The table below summarises these factors.

Table 16 Survey evidence of market and system failures associated with IS

Failures		Evidence from the stakehoders consultation
Market failures	Externalities	Risk and uncertainty about benefits Difficulties to assign benefits High transaction costs High technological lock-in costs
	Information asymmetry	Lack of knowledge on resources and waste streams generated by others
	Market power	Low margin and high uncertainty of IS projects Low prices for raw material
System failures	Network	Coordination of inputs/matching of timing is complex High negotiation costs
	Capability	Lack of technical expertise to identify potential Low abilities to change procedures and processes needed for IS
	Infrastructural	Dispersed production sites (causing high transpotation cost) Difficulties to arrange storage spaces Other organisational barriers
	Institutional	Regulatory barriers High dependence on governmental intervention, support, funding

Source: authors

Companies are not always convinced about IS due to perceived risk and uncertainties on its benefit. Initiating the IS practices comes with costs that companies are not always happy to bear. Many are still comfortable with business-as-usual practices in dealing with the waste and not open to invest in changes. The information about secondary resource streams and the chemical contents are not available for potential buyers. In addition, it is not always the case that the profit margins are highly attractive or even secured to make a business case for joining the IS enterprise. Low prices for raw materials are not contributing to the competitiveness of the alternative.

System failures that the survey respondents and interviewees identified were related to the lack of capabilities to coordinate and negotiate, and find matching conditions. Often companies do not know how to identify potential that can be offered by synergies and have low abilities to change business-as-usual practices. IS systems need infrastructure and logistical arrangements that need time and investment to organise. In most of the cases the IS ventures rely on governmental support.

Bearing in mind the contribution that IS cases have made to environmental goals, and its yet untapped potential, there is thus a strong argument that specific regulations need to be adjusted to allow favourable conditions for IS and tackle market and system failures.

7. POLICY OPTIONS TO ADDRESSING BARRIERS TO IS

Departing from the findings of the mapping and market analysis, which showed substantial untapped market potential for industrial symbiosis in Europe, the key question is what policy instruments can be designed and implemented to fulfil this potential. Drawing on the classification of networks, there are **three key policy approaches to promote IS**.

The first type of approach is to **promote the emergence and development of self-organised activity.** In this case, synergies are the result of spontaneous interactions between industrial firms motivated by economic drivers and market interactions. Spontaneous IS has shown resilience and adaptability over time. A case like Kalundborg demonstrates ability to adapt to changes both in the mix of organisations involved and the content of the synergies. Policies to promote self-organised activity need to focus on defining adequate framework conditions. The literature in the field as well as the findings from the analysis support this idea. Contextual factors defining the institutional framework in which firms operate affect the likelihood of IS emerging and developing over time. Some authors have referred to these factors as the economic, cultural, social and material embeddedness (Boons and Baas, 2007) in a specific area or region which affects the way in which firms interact and the types of interaction they engage in. Policies can play a significant role in defining favourable framework conditions and addressing system and market failures, eliminating persisting barriers and creating incentives for companies to engage in IS. In fact, existing cases of IS across countries have been largely indirectly driven by policy interventions ranging from emission control measures to increasing the cost of landfilling (e.g. landfill tax).

Second main policy approach draws on **planning initiatives to promote the development of Eco-Industrial Parks** (or restructuring of industrial areas into eco-industrial parks). Programmes with the mission of nurturing eco-industrial parks and promoting IS networks in existing industrial parks/agglomerations have been deployed in different parts of the world with different degree of success. These include initiatives in the USA, eco-parks in China (including the development of eco-industrial park standards) and South Korea (eco-industrial park programme), the Centre for Sustainable Resource Processing in Australia or the Eco-Town programme in Japan. Some of the earlier programmes in the USA and attempts in Europe have reported limited success, due to a number of factors, such as attracting complementary activities. However, in recent years, efforts in countries such as Korea and China have proven extremely successful. One main difference is that they are complemented with stringent policies and instruments (some of them which would be difficult to replicate in the Western countries) for the promotion of IS synergies. An increasing body of literature has reported substantial benefits associated with planned initiatives in those countries (see, for example, Dong et al., 2014 or Behera et al., 2012).While the impact of eco-industrial park programmes has been relatively well studied, discussion of policies in a broader sense to promote IS, have been insufficiently addressed by the literature in the field.

The third main policy option is what has been called 'the middle-out approach' (Costa et al., 2010). It proposes a **combination of facilitation and curated interaction** and shares characteristics of the self-organised activity. The main difference is that it requires a third party to help stimulate emergence and development of the network and to try to overcome barriers linked to information deficits and lack of technical capability. In this case, policy measures generally refer to promotion measures to help support intermediary coordinators.

In any case, one main findings of the review of case studies and analysis of interviews suggest that without adequate framework conditions, other support measures, such as direct facilitation of IS and planned IS, would have suboptimal impact. As shown in Table 18, facilitation addresses a large array of market and system failures, including externalities related to the uncertainties of assessing benefits of IS, information asymmetry, network and capability-related issues of the local companies to engage in more technologically advanced IS synergies. Nevertheless, several significant failures cannot be tackled by facilitation, especially when it comes to the low price of raw materials and the modest margins that result from some IS projects within existing fiscal, environmental or waste policy frameworks at EU or MS level.

Policies such as landfill taxes and landfill bans and stricter environmental regulations seem to be common contextual features that influence the emergence of industrial symbiosis and seem to be complementary to IS facilitation.

Table 17 Overview of case studies on policy options to addressing market and system failures

Types of failures		Evidence for IS	How IS facilitation tackles the failures	Selected cases
Market failures	Externalities	Risk and uncertainty about benefits of IS synergies Difficulties to assign benefits High technological lock-in costs	Technical assistance, expertise, feasibility studies	FISS Danish IS Programme SMILE Ireland
	Information asymmetry	Lack of knowledge on resources and waste streams generated by others	Matchmaking workshops Online platforms	FISS, PNSI France, ENEA Italy, INEX France Danish IS Programme Flemish Symbiose Platform NISP (UK, HU, RO)
	Market power	Low margin and high uncertainty of IS projects Low prices for raw materials	-	-
System failures	Network	Coordination of inputs or matching timing High negotiation costs	Ensuring confidentiality, neutrality and building up trustful relationships.	SMILE Ireland, FISS, NISP (UK, HU, RO) Catalisti
	Capability	Lack of technical expertise to identify potential Low abilities to change procedures and processes needed for IS	Technical assistance, expertise, feasibility studies	FISS, SMILE Ireland, Danish IS Programme, INEX France, NISP
			Innovation support	FISS; EYDE
			Open Innovation facilitation	Catalisti cluster Flanders
	Infrastructural	Dispersed production sites Difficulties to arrange storage spaces etc.	-	-
	Institutional	Regulatory barriers High dependence on governmental intervention, support, funding	Liaison with govt. to find solutions for regulatory barriers (e.g. EoW)	SMILE Ireland NISP UK

Source: authors

Based on these policy options and drawing on experiences with policies supporting IS collected in case studies and interviews with policy-makers, policy instruments to stimulate IS facilitation and synergies more broadly can generally be classified into two different types of measures:

1) **Direct support measures,** which have as main aim the support/promotion of IS activity itself, may include: (a) support to the creation of facilitation hubs; (b) market instruments specifically aimed at directly supporting IS projects (tax breaks, subsidies, etc.); (c) promotional instruments to support company awareness/communication/networking; (d) planning instruments to promote IS at the local and regional level.
2) **Indirect support measures**, that while not having a specific IS support mission, can create adequate framework conditions to favour the spontaneous emergence of industrial symbiosis, including standards and regulations (e.g. landfill bans, incineration bans, emission standards, definition of by-products, 'End of Waste' criteria), market instruments, such as landfill taxes, research and development and other instruments such as promotion of secondary markets or GPP.

Both types of measures can be used in complementary ways to support IS activity, be it self-organised, planned or facilitated.

Given the focus of this study, the review of policy options will focus on key instruments that have been highlighted during the consultation with stakeholders and identified as critical in the review of existing literature and case studies. The policies cover both direct and indirect support instruments. Most of the indirect instruments are related to setting suitable framework conditions for IS and addressing some of the current barriers.

The box below provides a snapshot of the types of policies analysed under this study.

Figure 27 Types of policy instruments for stimulating IS

Types of policy instruments to promote industrial symbiosis

DIRECT SUPPORT

Strategic investment (including R&D and planning instruments)

- Support of regional networks
- Risk finance
- Promotion through regional planning instruments
- Integration of IS principles in activity permits for IPPC activities
- Subsidies/ support mechanisms for feasibility studies investment related to IS projects
- R&D directed towards: 1) technologies and 2) social-organisational innovation

INDIRECT SUPPORT (Adapting framework conditions)

Regulatory instruments (Standards and engagement)

- End-of-waste criteria: clarification and streamlined procedures
- Landfill bans and landfill diversion targets
- Internal market for recovered materials or material flows
- Eco-design: criterial for recyclability, use of secondary materials and consideration of end of life
- Standardisation/homogenisation of the secondary materials
- Clarification of legislative framework for new business models (e.g. leasing)
- Better waste segregation to maintain material purity

Economic instruments (Markets and pricing)

- Policies increasing the cost of landfilling, such landfill taxes
- Resource taxes (e.g. embedded carbon tax)
- EPR schemes with differentiated charges

Other instruments (and voluntary approaches)

- Green Public Procurement - development of technical criteria as an incentive for IS in the public sector
- Green supply chain schemes/ initiatives
- Training actions to MS officials/ businesses
- Harmonised standandards and metrics for IS facilitation activities

7.1. Direct support to facilitation of industrial symbiosis

One key finding from the study points at the need to tackle current barriers to IS through a combination of direct and indirect instruments. Within direct approaches the study has concentrated on facilitation, direct investment or financial support schemes and planning instruments to promote IS. Main findings are summarized in the sections below.

7.1.1.Support to regional or national networks

Facilitated networks have mainly relied on funding from the government to develop IS cooperation, as presented in the previous sections on IS – either through national programmes (such as the NISP UK, FISS Finland, PNSI in France, SMILE Ireland, Danish Green Industrial Symbiosis Programme, ENEA Italy) or at regional level (e.g. Catalisti in Flanders – former Symbiose Platform). Programmes in Hungary and Romania have been developed with the help of EU funding on a project basis, but implemented at regional level.

Apart from NISP UK, many of the programmes are fairly new and have not undergone evaluation. The first results from the French PNSI, for example, have just been released at the end of November 2017. As noted before, funding for facilitation tends to be short-term, and in many cases, there is the expectation that networks will evolve fully-fledged commercial ventures. However, commercialisation of IS programmes have proven extremely problematic, with no current evidence of third-party facilitation, beyond waste-exchange web-based tools (albeit unsuccessfully in terms of scale and range), which works on a fully commercial basis. There are two main questions to consider: 1) Is facilitated activity necessary to promote IS is adequate framework conditions are in place? 2) Can the ROI of facilitation justify public support compared to other alternatives? There is no a clear answer for these two questions. In the first case, one should consider whether facilitation is speeding the process of synergy realisation, by for example, providing support to parties involved. In the second case, better monitoring of performance of facilitated activity and common reporting guidelines are required to accurately assess impact and ROI.

Mixed approaches such as public-private partnership, which have worked well in self-organised and planned activity, could be worth exploring. Also, the role of facilitation could be embedded into existing structures such as cluster organisations or, as will be described in more detail later, IPPC officers.

A key characteristic of facilitated IS programmes has been regional scope and decentralised models of operation even in nation-wide programmes. Examples of national programmes with regional level implementation with support of regional authorities/agents include FISS in Finland, the Danish Green Industrial Symbiosis Programme or the French PNSI. It is also common for programmes to access direct funding from several sources on a project basis, as in the case of the Italian network, coordinated by ENEA.

Most of the programmes have been using a similar approach to promoting IS, which builds on: 1) creating awareness of potential and nurture a social network; 2) identifiying potential for energy, material and water synergies; 3) supporting the implementation process of synergies from inception through competition. Based on the NISP blueprint most initiatives have included the build-up of a database of potential matches and attraction of companies to the network through cold calls and the organisation of matchmaking workshops. Some of them, like the Danish Green Industrial Symbiosis Programme, also offered small grants (up to €25 000) for feasibility studies (estimating the economic, legal or technical issues of the matches). While in most cases, facilitated programmes have reported a good level of engagement and attendance to workshops from the companies, impact has been less consistent, with examples of high performing initiatives, such as NISP, and cases where a lower than expected share of the potential synergies were actually implemented. This seems to point to: 1) deficiencies in the way some of the programmes have been implemented; 2) lack of consistency across assessment, monitoring and reporting frameworks and 3) the critical aspects of adequate framework conditions to support IS implementation.

Table 18 Selection of publicly funded programmes offering direct support to facilitation and system failures tackled

Programme name	Mode of implementation	Main driving organisations	Failures tackled
PNSI France	Nationally and regionally co-funded programme: Matchmaking workshops Technical assistance to assessing potential of synergies	Institut d'economie circulaire ADEME Ministry of Environment 4 regions in France	Networking Information asymmetries Capabilities (Expertise to identify synergies and assess costs and benefits of synergies)
FISS Finland	Facilitation of networking & workshops Support for technical assistance Linkage with investors and public funding	Finnish Ministry of Economy Motiva	Networking Information asymmetries Capabilities (expertise to identify and tackle synergies) Access to finance
Danish Green Industrial Symbiosis Programme	Nationally funded programme Facilitation of networking & workshops Small grants (up to €25k) for technical assistance to assess potential for synergies	Danish Business Authority 5 regions in Denmark and Municipality of Bornholm	Networking Information asymmetries Capabilities (expertise to identify synergies and assess costs and benefits)
SMILE Ireland	First stage: Facilitation of networking & matchmaking;	Irish Ministry for the Environment Macroom-E 3 Regions	Networking Information asymmetries
	Second stage: Technical assistance to identifying and implementing synergies through		Capabilities to implement synergies
Flemish Symbiose Platform	First stage : Facilitation of networking & matchmaking ; Resources database	Flemish Agency for Innovation and Entrepreneurship FI-SCH cluster (now Catalisti)	Information asymmetries Networking
	Second stage : innovation support to synergy implementation	Catalisti	Information asymmetries Capabilities (implementation of synergies)
NISP Hungary	LIFE+ Project Facilitation of networking and matchmaking Support to assessing materials flow in companies Resources database	IFKA Hungary	Information asymmetries Networking Capabilities to identify synergies
NISP Romania	LIFE+ Project Facilitation of networking and matchmaking Support to assessing materials flows in companies Resources database	Romanian Ministry of Enviornment ECOREG	Information asymmetries Networking Capabilities to identify synergies

Source : authors based on case studies and interviews; please refer to section 2 for full overview of facilitation in Europe.

The **majority of the funded programmes have focused on tackling the market failures related to information asymmetries**, responding to the companies' lack of knowledge on resources, by-products and waste streams generated by others. The **systemic issues tackled** were in the majority of cases: a) the needs for **networking** (covered through matchmaking events) and b) the companies' low **capabilities to identify and assess the potential of synergies** (covered through offering technical assistance for consultants assessing material flows in companies or costs and benefits of synergies). However, the negotiation and implementation of synergies has been left in the majority of cases to the private sector actors. This may partly explain the low level of implementation of potential synergies. Programmes that have offered support in the implementation phase, beyond potential identification, such as NISP UK or IS NI, seem to have achieved better results in terms of completed synergies.

To sum up, while the programmes have been considered successful in starting the conversation and connecting companies for potential IS matches, the facilitation of the synergy implementation stages needed more emphasis and an integrated approach. The feedback received from the stakeholders points to the fact that simple matchmaking is not enough to reach actual economic and environmental impacts. Synergies tend to take time and in many cases involve changes to business practices or innovation. An element that was stressed in the interviews was the **lack of time and lack of capabilities of companies to go through the different stages of development of synergies**. This supports findings from the literature that note ***'absorptive capacity'* as a key factor affecting the feasibility of IS transactions** (Schmiegelow and Andersen, 2016). Some facilitation programmes, such as NISP UK, providing support through the IS development from inception to realisation have proven more effective at creating impact but support has been more fragmented in programmes funded on a short-term basis or with less resources. The **capabilities of companies to develop projects related to IS is thus an area in need of support**. As mentioned earlier, **technological barriers** are also important bottlenecks in implementing synergies, which may require further public intervention, through R&D programmes and ad hoc support to demand-driven innovation.

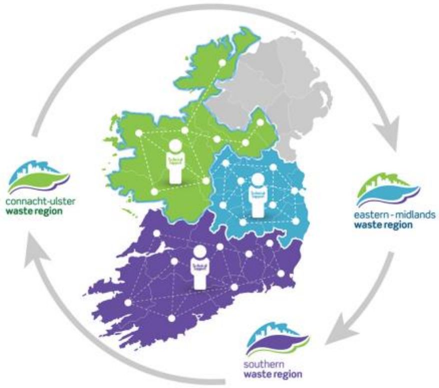
The internal capability, expertise and, very importantly, professional networks of IS practitioners have also been highlighted in the interviews as elements impacting the ability of the programme to forge alliances with companies. These elements are key in understanding company's mission, priorities and access points and understanding technical and economic challenges of IS implementation.

While direct financial support through short term programmes such as H2020 or Life+ had proven of limited effectiveness in setting the networks and upscaling them, there are opportunities for IS networks to be integrated into broader regional development strategies and benefit from financial support through INTERREG and regional funds. European funding such as ERDF, while welcome to support industrial symbiosis, is more activity based in terms of metrics rather than output/impact based. Thus, it is of limited value for learning about the effects of the programmes. It should also be noted, as pointed out above, that IS facilitation roles can be adopted by existing business service networks in regions or be supported through cluster organisations. This, however, requires capacity building at local and regional level on IS.

Figure 28 Case study: SMILE Resource Exchange Ireland

SMILE Resource Exchange

The SMILE programme started off as a platform for connecting companies for exchanging excess resources. This didn't require much expertise, as the material exchanges were not very difficult, and therefore the methods employed by the platform for facilitation were simple (including phone interviews, building the database of companies and resources that can be transacted, matchmaking workshops). An additional engagement tool that the SMILE network used was to develop stories on results of companies that have been involved in synergies, in order to inspire network members.



Nevertheless, as SMILE was not offering technical assistance to implement IS synergies in the early stages, not many IS projects were being completed. With time, SMILE recognised the value of larger networks and the potential for more complex IS transactions, by learning from other European networks' examples.

In order to scale up, the programme was changed and stopped organising matchmaking events, which were effective in obtaining first contact between companies, but highly work intensive to organise. In order to concentrate the limited budget on higher-return support services for businesses, the programme hired three consultants, one in each of the regions in Ireland where they have partnerships. Consultants are contracted on a yearly basis, part-time to work with companies on facilitating IS. Consultants are in general selected based on their already existing services for and network of companies. Their role is to try to bring IS and the SMILE dimension to companies. The consultants are the ones identifying new companies, connecting the companies every 2-3 weeks to discuss the synergies and updating themselves on the potential.

The website services of a sharing platform have been maintained in their simplified version. There, for example, a large company trying to donate furniture can connect to organisations who can reuse that. This type of exchange does not require expertise of consultants and is resolved through facilitating the contacts between supply and demand on the platform.

However, in order to undertake larger scale IS projects, the role of the technical consultants in mobilising the companies was believed crucial.

Source: authors based on interviews with facilitators.

7.1.2. Investments supporting IS synergies' implementation

In some cases, facilitation programmes were accompanied with support schemes for the realisation of identified synergies through technical assistance, feasibility projects or R&D grants. This happened, for instance, in the case of the Flanders Symbiose Platform, where R&D partners were matched with industrial partners to develop the synergies in collaborative projects. The organisation developing NISP Hungary also identified technological barriers in the implementation of synergies, which resulted in a new project (EUR-IS, funded by the Climate-KIC pathfinder programme), which focused on supporting technologies for the more complex synergies identified. In the case of SMILE Ireland, technical assistance has been envisioned as part of the second stage of the programme, with experienced experts guiding companies in the identification and early implementation of the synergies. In the case of NISP UK, NISP practitioners partnered with the Knowledge Transfer Network to provide expert advice on a number of technological challenges and forged collaboration between academia and research centres and businesses, leading to demand-led innovation, although the programme itself did not cover financial support for synergy implementation.

The importance of the existence of support for demonstration and implementation was also acknowledged by representatives of the Danish Green Industrial Symbiosis programme, which was discontinued after 2015. The programme, which may be re-launched, requires a stronger focus on providing support to companies' capabilities to implement IS synergies, in order to increase impact. The first review of the Finnish IS programme FISS published in 2013 reached a similar conclusion, and recommended that, next to identification of synergies, actual support to pilots and demonstration cases need to be promoted. Pilots should bring together a range of stakeholders including IS solution providers (and new technologies) with clients, from Finland or abroad (Sitra, 2013).[32] This could happen e.g. through business development tools, capital investments, or support for internationalisation, especially in the case of SMEs (ibid). As a consequence, the post-2014 version of the FISS programme has included a component of financial support to synergy co-development and cooperation. So far, as mentioned earlier, 200 synergies have been identified since 2014, 600 companies have been mobilised, while 10 regional symbiosis demonstration projects are ongoing. Support to innovation and technology development was also a core component of the services offered by Catalisti network in Flanders, as describe in the box below.

There may be important overlaps between **IS and cluster support policies**. The mapping exercise has identified potential for IS in European clusters and, in fact, examples of IS self-organised activity tend to coincide with clusters of industrial activity. Findings have pointed to policy options to promote IS through clusters and supply chain approaches. Both approaches could be combined to promote the formation of circular value chains through **cluster support** to foster industrial symbiosis. In a targeted survey with clusters managers, resource efficiency is ranked as an important driver for cross-clustering opportunities by almost 50 % of the clusters, the second most important trend facing clusters after "smart everything" (ECO, 2015).[33] In Europe, the concentrations of circular economy related industries[34] is spread evenly across regions, with the largest concentrations in France, Italy and Poland (ECO, 2017).[35] Nevertheless, the European Cluster Observatory only identified four top locations specialised in this field, with only one of them displaying high-value specialisation (including a high degree of R&D and innovation activities) (ibid, 2017). This points to untapped opportunities to increase CE specialisation in clusters and opportunities to do so through adoption of IS approaches.

In line with the findings of the European Cluster Observatory on the importance of resource efficiency as an opportunity for clusters, and given the close ties clusters have with member companies, this type of organisation have often been involved in partnerships for facilitation of IS, either in self-organised, planned or facilitated ventures (e.g. EYDE Cluster in Norway, FISCH / Catalisti Cluster in Flanders, AXELERA cluster in Rhone-Alpes region, GreenTech Cluster in Styria etc.). Despite this potential, the study has been unable to identify many clear cases of national or regional support policies targeting clusters as facilitators of IS. This could be an area worth exploring. Policy options here could cover a wide range of instruments from facilitation through cluster organisations (e.g. Essentia in Belgium) to more far reaching policies including incentives to CE acivity, voluntary targets and standards for environmental performance.

Future research is needed to unveil the potential for IS in European clusters in terms of key resources, technologies and policies. It should also identify opportunities to integrate IS practices / principles in clustering activities led by cluster coordinators.

---

[32] Sitra (2013) : Arvoa ainekierroista – teollisten symbioosien globaali markkinakatsaus. Commissioned from Gaia Consulting, authored by Aho, M. et al ; in Johnsen (2016), p. 33.

[33] European Cluster Observatory, 2015: Foresight report on industrial and cluster opportunities,

[34] Circular economy related industries included are the maintainance and repair industries (e.g. of motor vehicles, machinery, computer and peripheral instruments etc), environmental services, water transportation and transportation and logistics.

[35] European Cluster Observatory, 2017: Priority Sector Report, Circular Economy

Among the few examples identified as potential good practice for integrating IS in cluster activities (although it does not target it directly) is the **Flemish Spearhead Clusters policy**, through the Catalisti cluster. Since the beginning of 2017, the renewed cluster support in Flanders targets the development of value chains in strategically important domains (e.g. such as chemicals and bio-based products) through the long-term support of 'spearhead clusters'[36]. Through this new regional clusters programme, the Catalisti cluster activities are following up on the Flanders Symbiose Platform[37] continuing the demonstration of some of the identified synergies. The activities of the cluster offer an example of an approach to **fostering industrial symbiosis through promoting collaboration between business, academic and public sector partners**, in a triple helix setting. The cluster now focuses more on hands-on technical assistance and "account management", whereby technical experts are contracted for the duration of the programme to assist the companies in the identification and implementation of more complex projects. An important element is the emphasis on **risk-sharing in the investments needed for implementing the projects**. Half of the budget is secured by the public sector, while private partners contribute the other half. This ensures the end-user focus and ownership of the activities' results.

Figure 29 Case Study: Symbiose Platform and Catalisti cluster Flanders

Symbiose Platform

The Flemish Agency for Innovation and Entrepreneurship funded the Symbiose Platform between September 2012-December 2015. Catalisti was actively part of the implementation of the September 2014 to December 2015 Symbiose Platform project, (in its previous format, as FI-SCH).

Symbiose's facilitation methods included awareness raising, matchmaking events and the development of a database of 300 organisations from Flemish industry. As an output of these activities, the database mapped 2000 opportunities for flows of raw materials and technologies that could happen between companies. Of these opportunities and links created, some 500 were followed more closely with a feasibility study or analysis. Of these, there were 15 companies where a successful match could be identified in terms of economic and environmental gains. The total potential economic gain was estimated at more than €1 m/year.[38] However, these links then needed to go through the negotiation and testing phase, which was out of the scope of the support offered by the Symbiose Platform. For this reason, they were no longer documented by the platform. The known gains based on the follow-up of the managers of the platform are considered to exceed €2.5 m in cost savings for the companies that progressed in the implementation.

One of the reasons why only 15 companies out of the 300 participants in the database were identified as successful matches, is believed to be the limited sectoral scope of the platform, which was mainly focusing on the chemical and biobased products sectors. The programme was therefore renewed in September 2017, opening the platform for exchanges across more industries, in order to achieve cross-sectoral synergies. It is too early to assess the results of this change in the Symbiose Platform strategy, and a follow-up evaluation is needed.

Catalisti - open innovation and its potential for IS support

Previously, the FI-SCH cluster had been funded by the government up to a share of 80 % of their budget. Since 1st Jan 2017, the cluster transformed into Catalisti with a new legal construction, after being selected as a Spearhead Cluster by the Flemish government. The cluster was awarded with a ten-year commitment of support, and a

[36] See Vlaio, 2017 : http://www.vlaio.be/themas/innovation-clusters-flanders
[37] the platform was a project of the former Flemish Sustainable Chemicals FI-SCH cluster, since January 2017 called Catalisti cluster.
[38] See Catalisti, 2016: http://catalisti.be/project/symbiose/

budget of €500 000 per year. This budget needs to be leveraged with project-based co-funding by companies.

After managing the Symbiose platform, the (now) Catalisti cluster decided to change the model of facilitation and not focus on the matchmaking events and the online resources database, due to the high staff effort intensity required in the communication activities, with less than expected results in the Flemish context. In this new format, the cluster keeps IS as one of its potential focus points, and continues to support it through open innovation and facilitation of cooperation between public-private-academic partners. However, their target has moved "downstream" on go-to-market support for companies. In this new model, the ownership and governance is highly controlled by companies.

At the same time, Catalisti has also broadened its scope, and is no longer only focused on industrial symbiosis projects, but generally on innovation brokerage for projects related to renewable chemicals, sidestream valorisation, advanced sustainable products and process intensification.

The new approach of the programme is the closer engagement with the companies, based on the "triple-F approach": find innovative opportunities, facilitate their development based on expertise and access to resources, and fulfil the cooperation initiatives in partnership[39]. Two persons employed on a full-time basis are 'account managers' for a group of companies, and follow up the development of projects.

Source: authors based on interviews with facilitators. A full version of the case is provided in the annex.

Based on the experience of the reported cases, approaches to supporting IS can also draw on experiences from innovation support policies targeting the development or commercialisation of green growth technologies or business models, as well as funding programmes that support resource efficiency.

Many Member States have prioritised resource-efficient production and consumption, the circular economy and in some cases also IS-related activities in their innovation strategies. Nordic countries, in particular, provide examples of how public funding for innovation can be a source for implementing IS projects. In Finland, the Research and Innovation Agency Tekes and Sitra – the Finnish Innovation Fund - have strengthened their cooperation in supporting circular economy solutions and green business models. Moreover, through FISS, there was an integrated support to co-creating and development of the synergies through technical assistance. In Sweden, even if IS is not the main policy goal, major innovation support players such as Vinnova, the innovation support agency, the Energy Agency and Formas are cooperating in implementing the government's Production 2030 vision for manufacturing activities, which prioritised the support for "environmentally sustainable production".[40] The funding programmes that have been launched within the framework include support to testing and demonstration facilities for the digitalisation of the Swedish manufacturing industry through the lens of resource efficiency as well. Since 2016, the Swedish RE:Source programme, part of the same strategy, is providing funding to the development of innovations that can lead to a more efficient use of resources in businesses or in the society as a whole.[41] Since

[39] See Catalisti, 2017: http://catalisti.be/triple-f-principle/

[40] See Teknikföretagen, 2013: Made in Sweden 2030, Strare gic Agenda for Innovation in Production, https://www.teknikforetagen.se/globalassets/i-debatten/publikationer/produktion/made-in-sweden-2030-engelsk.pdf

[41] See RE:Source, 2016: http://resource-sip.se/om-resource/resource-in-english/

these programmes have not been evaluated, it is too early to draw conclusions on their performance, nevertheless, it is important to note their potential to support IS.

The European Investment Bank has identified **risk-finance** as a missing link in the support framework for industrial symbiosis in the EU (EIB, 2015). Due to the higher risk that investors and banks associate with such collaborative endeavours, the cost of capital is higher for IS project implementation. This is why the provision of finance through various financial instruments such as grants or loan-guarantees to banks was recommended for initiatives developing IS or 'circular value chains' projects, which would require high upfront costs for projects related to relocating plants, building new distribution and logistics networks, retraining the workforce, or re-adjusting the production equipments so as to become more compatible with the downstream partners' requirements (EIB, 2015).

7.1.3.Regional and urban planning in support of IS

In general, there are not many countries that prioritise direct support for IS on the planning policy agenda. Nevertheless, some regions have taken initiative to support bottom-up approaches to IS, often without directly targeting IS, but allowing companies and business parks to self-organise into IS networks (Johnsen (ed), 2016).

There are examples where IS has developed spontaneously at regional level or has been planned as part of eco-industrial parks, becoming embedded in local and regional planning. However, in most instances this has happened independently of formal planning processes. For instance, IS enjoys strong public support in the Kemi-Tornio region (Lapland, Finland), where the Kemi-Tornio Technology Park has been a key facilitator. The region provides direct support to the technology park, "due to the potential of sustainable natural resource use to support regional development by adding value to Lapland's exports" (Johnsen (ed), 2016). Moreover, the region also invested in a mapping exercise revealing the potential of IS in the area – which reinforced the interest in promoting this work. There is, however, a need for a "long-term and systematic role for a competent and trustworthy intermediator", which can carry forth the IS network facilitation (ibid).

Other examples have been documented in Swedish regions, where, in spite of the lack of a dedicated programme at national level, networks of companies have been created to support synergies involving materials or energy flows. Cases include the municipality of Lindköping, Helsingborg, Enköping and Stenungsund[42]. In many cases, these are connected to primary sectors such as pulp and paper and energy production.

Several cities such as Amsterdam, Malmo and Rotterdam have made efforts to support the development of industrial symbiosis in port areas, where major industries are located. In Malmo, the focus has been on energy systems and re-utilising heat flows. Through the Shared Energy project, the city of Malmo is demonstrating ways to create conditions for IS and cleantech, which could later be mainstreamed in other future urban planning projects.[43]

In the case of Rotterdam, the scope of the IS activities spans the entire harbour and the city of Rotterdam (10 by 40 km). According to interviewees, energy efficiency and sustainability are shaped in an IS fashion with a new steam network in the "Botlek", a part of the Rotterdam harbour: the excess steam from waste processing company Afval Verwerking Rijnmond (AVR), part of Van Gansewinkel Group, forms the source of energy for other businesses. AVR will also supply its waste heat via pipelines to the city of Rotterdam for district heating purposes.

IS in port areas benefit from a concentration of activities in a constrained geographical area and their inter-connection through the port authority, which provides an overarching framework for activities. There have been attempts to replicate this in other port/harbour areas in initiatives such as ECOPORT or EPIC 2020[44]. These EU-funded

[42] See http://www.industriellekologi.se/symbiosis/reports.html
[43] See Delad Energi / Shared Energy, 2017, http://deladenergi.se/startsida/
[44] See http://www.epic2020.eu/

projects have focused on identifying potential for resource efficiency, circularity and bioenergy through application of IS approaches to port areas. Results have pointed to untapped potential for industrial symbiosis. However, at the same time, there is a lack of high quality data as a main barrier for the identification of potential, as well as of committed facilitators willing to invest the time and effort required to build a network and maintain interest of stakeholders. There is a need for well-developed case studies that show value creation through industrial symbiosis in port areas.

The Basque Country is an example of regional effort to promote the circular economy, including supporting IS-related activities, and working with a systemic approach towards improving framework conditions for businesses to take up circular economy practices (Ihobe, 2016)[45]:

- The Basque government approved a plan for Green Public Procurement in September 2016 – which includes the development of technical criteria for 'green' purchasing in the public sector – especially in the field of construction and public works
- Moreover, the Basque country incentivises green supply-chain management especially in larger companies – who should be shifting to purchasing (and producing) greener products and services.
- Developed technical and environmental standards as foundation for demand and supply for secondary materials and sustainable products – e.g. the 2015 regulation on the "requirements for the use of aggregates deriving from the recovery of demolition and construction waste".
- Issued the framework for Environmental Consents and Inspections of industrial and waste management activities – which foresees that the companies are legally bound to demonstrate there is no recycling alternative for their waste before it can be accepted in a landfill – and obtain consents from landfill sites and recycling facilities. Moreover, since 2009, the dumping of waste flows for which there are recycling and recovery alternatives is prohibited.

A particularity of the Basque country approach is that they use the knowledge of IPPC activities to promote regional synergies. This unique approach to governmental facilitation has proven extremely successful in a small region with a relative higher share of manufacturing activities such as the Basque Country. This approach intends to favour better use of resources and align planning and licensing activities with IS opportunity identification and realisation. Stakeholder consultation has provided support to measures that this which could potentially have a high impact, as IPPC activities generate the largest proportion of industrial waste. This however requires: 1) good, accurate data on IPPC activities and key resource flows, something that should in any part be accessible as part of the IPPC process and 2) technical capability at the regional/local level to be able to understand potential and negotiate with businesses feasibility of implementation.

Urban approaches to industrial symbiosis have also attempted to pervade IS principles into planning processes. As part of the INTERREG project TRIS[46], Birmingham has identified opportunities to foster synergies within the city that harness existing resources. Birmingham's Big City Plan is also an example of a planning document that includes industrial symbiosis principles in the city development strategy.[47]

Another example of incorporating industrial symbiosis into regional development strategies can also be found from Turkey, where it has been included as a priority tool for reaching regional competitiveness and eco-efficiency goals in 19 out of 26 regional development plans prepared by regional development agencies. The Turkish national

[45] Ihobe, (2016): "36 Circular economy demonstration projects in the Basque country. Results from business initiatives"
[46] See https://www.interregeurope.eu/tris/
[47] See Birmingham City Government, Birmingham Big City Plan 2013 http://bigcityplan.birmingham.gov.uk/wp-content/uploads/2013/01/Economic-Zones-Prospectus.pdf

government introduced IS as a strategic tool to achieve environmental goals in its 10th and 11th Development Plans. It is important to note, however, that these initiatives have not been evaluated and implementation has only been initiated in a reduced number of pilot regions.

Based on the literature and/or practical examples of implementation, a number of further planning instruments can also play a role in promoting IS:

- Planning waste and valorisation infrastructures based on materials flow analyses to better match resource availability with recovery technologies
- Infrastructural plans can also take into account IS principles that not only foster current potential for IS but maximize future potential through provision of key infrastructures (i.e. IS principles introduced in planning processes in Basel, Birmingham and Turkey).
- Strategic Planning of scarce and critical materials may also consider IS potential (Mineral strategic policies – e.g. Sweden).
- More importantly, industrial symbiosis principles should be embedded into Industrial Strategy documents to fully unveil regional synergies and value creation through better use of resources and strategic clustering of activities to maximise value extraction from resources.

Further research is needed for the analysis and evaluation of results of initiatives embedding IS principles in industrial strategies through strategic planning and clustering of IS activities in regional settings (e.g. Germany, Austria, Flanders).

7.1.4.Summary assessment on direct support to IS

There were several common lessons learned from the programmes and interviews with the managers of the programmes, which can be summarised as follows :

- Raising awareness and matchmaking events are not sufficient as the only types of support for actually realising the identified opportunities for IS
- Due to the fact that the by-products identified for opportunities for synergies may need further treatment and testing in order to be used in the receiver company, the time from identification of matches to full implementation may take even 12-18 months or more for the more complex challenges.
- Depending on the complexity of the matches, the process of implementing the synergies takes a similar route to innovation projects, which are based on an iterative process of testing, development, demonstration.
- Further features of the programmes such as direct guidance from technical experts and innovation brokers are considered very helpful in accelerating the implementation of synergies.
- The actual implementation of the synergies may need to be accompanied by further incentives for the companies entering in the testing phases.
- Cluster support policies and public-private-partnerships can be alternatives to incorporating IS
- Planning approaches to foster IS through regional policies have proven highly effective in promoting bottom-up identification of IS opportunities by companies in negotiation with public authorities
- A more ambitious and proactive application of IPPC regulation to encourage identification of regional IS potential could create important incentives for IS at regional level. IPPC activities generate a large share of industrial waste and, therefore, practical impact could potentially be substantial. Application, however, requires efforts to increase capacity of regional officers, including both understanding of technical issues and negotiation skills with businesses

In summary, a review of direct support policy options suggest a need of prioritisation of long-term support for circular economy and IS-friendly regulations (see next chapter) at EU/national/regional level. This can be complemented by direct support for IS activities at local or regional levels (e.g. for the development of networks and/ or clusters) (Johnsen (ed), 2016).

7.2. Indirect support measures for industrial symbiosis

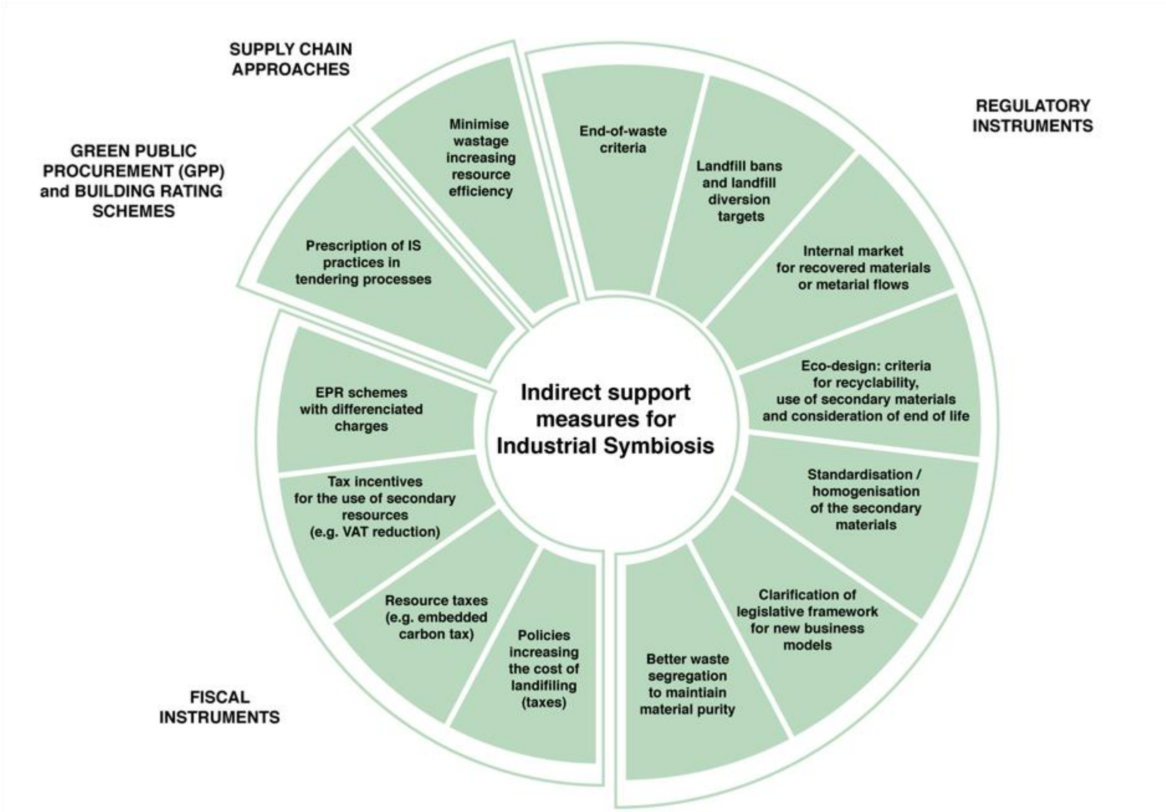
In IS networks, environmental benefits need to be accompanied by economic benefits (or costs savings for businesses). In fact, as stressed by the IS literature, economic opportunities acted as drivers in the emergence of established networks, such as Kalundborg (Cote and Cohen Rosenthal, 1998; Karlsson and Wolf, 2008; Tudor et al., 2007; Lehtoranta, 2011). IS has generated benefits over stand-alone productive activities by reducing the costs associated to waste management, generating new potential streams of revenues by selling by-products, or by reducing the acquisition costs of raw materials. Economic benefits may also emerge from the sharing of infrastructures, logistics and space (Chertow and Lombardi, 2005).

Economic drivers, however, are mediated by framework conditions (Domenech and Davies, 2010). Setting adequate framework conditions is a priority area that requires action by policy-makers at the EU and MS levels to drive IS activity. An overview of different types of relevant policy instruments influencing framework conditions for IS is provided in Figure 30.

Landfill taxes, for example, increase the cost of landfilling favouring the identification of landfill diversion strategies and making them viable. On the other hand, interviews have highlighted that low prices of virgin raw material compared to secondary materials (which may result from inadequate mechanisms to internalise pollution and impact costs in upstream activities) may deter further use of secondary materials. What is deemed cost-effective and economically viable is highly dependent on existing framework conditions.

Ambitious waste and environmental impact reduction targets and standards may also promote feasibility of IS solutions against more traditional waste management practices (Costa et al., 2010; Paquin and Howard-Grenville, 2009) by providing clear incentives for waste prevention and landfill diversion. Kalundborg is traditionally presented as a business-led network, however, it is also important to highlight that Denmark was the first country to have an environmental law and stringent regulatory framework on pollution control which defined suitable conditions to implement industrial symbiosis (Domenech, 2010). For example, some of the synergies in Kalundborg are the result of attempts to reduce sulphur emissions. Also important was a flexible approach to policy implementation and enforcement that left room for innovation. These two elements, stringent targets and flexibility in enforcement to support innovation have also been highlighted in the stakeholders’ discussions as crucial factors for promoting IS activity.

Figure 30 Indirect policy instruments influencing framework conditions for IS



Source: authors

The potential for IS revealed through the market analysis and the existence of market and system failures preventing IS application may justify the need for policy intervention in this area. The review of case studies also point to the need for balanced, well-designed and coordinated action covering both indirect and direct measures. The following sections review key framework conditions for industrial symbiosis. The empirical research has shown that success of direct actions is dependent on adequate framework conditions. Findings suggest that while policy and regulation have been important drivers in the uptake of IS solutions, they may create disincentives for IS collaboration (Domenech and Davies, 2011; Chertow, 2000), which prevent IS solutions. The current definition of waste in the European legislation has acted as an impediment rather than a driver for IS promotion, by increasing the administrative burden and perceived risks of transactions associated with waste. The necessarily broad definition of waste as something that the holder wants to discard creates uncertainties regarding the legal status of resources that no longer hold any utility for the holder but may be used by another activity as a substitute of primary raw material, with or withour undergoing a valorisation treatment. The review of the waste framework regulation has tried to address some of these issues and concerns. Already in 2008 the review of the Directive included the figure of by-product and EoW criteria. The distinction between a waste and by-product is further explained in the EC COM/2007/0059 final[48], which describes the differences between waste and by-products. However, as will be discussed later, transposition and interpretation has varied substantially. The latest review of the Waste Framework Directive (WFD) offers some response to these challenges in line with a stronger emphasis on circularity and development of secondary markets for materials.

The impact of these recent changes is too early to evaluate, but the survey and interviews provide some hints on actor perceptions about the potential impact of these changes in promoting industrial symbiosis and discuss some of the shortcomings of

[48] COM/2007/0059 final */ Available online at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52007DC0059

proposed instruments, such as end-of-waste criteria and definition of by-products (such as lack of harmonisation in their implementation).

The next sections provide an overview of key instruments, classified as regulatory, economic and other instruments (supply chain approaches and GPP).

7.2.1.Regulatory instruments

This chapter provides an overview of regulatory instruments which can support the diffusion of industrial symbiosis. As mentioned earlier, these include:

- End-of-waste criteria: clarification and streamlined procedures
- Definition of by-products as distinct from waste (Art. 5 of the Waste Framework Directive)
- Landfill bans and landfill diversion targets
- Internal market for recovered materials or material flows
- Eco-design: criterial for recyclability, use of secondary materials and consideration of end of life
- Standardisation/homogenisation of the secondary materials
- Clarification of legislative framework for new business models (e.g. leasing)
- Better waste segregation to maintain material purity.

The (2014) 'Scoping study identifyig potential circular economy actions, priority sectors, material flows & value chains' identified a series of bottlenecks that hamper the realisation of the circular economy based on empirical evidence from six priority sectors scoped by the study (Packaging, Food, Electronic and Electrical Equipment, Transport, Furniture and Buildings and Construction) (Ecorys et al, 2014). These broad bottlenecks include:

- Vagueness and lack of clarity in the language of legislation
- Insufficient information and awareness of legislation
- Unintended disincentives created through legislation
- Insufficient framework for implementation of legislation
- Insufficient optimisation resulting from competing priorities

A subsequent report on the regulatory barriers to the circular economy looked at further priority sectors and value chains (in fifteen case studies) and emphasised that, for the circular economy to advance and in order to allow companies to retain value and materials in Europe, the internal market for recovered materials or material flows needs to be harmonised (Technopolis Group et al, 2016).[49] Moreover, most existing legislation address externalities (such as the case of food waste or discarded electronic waste) through focusing more on the "end of pipe" solutions like treatment and disposal, instead of placing priority on prevention and reutilisation. On the whole, this means that the existing legislation is not stimulating the private actors to choose the solution attuned to the highest possible waste hierarchy and in many cases favours (energy) recovery over recycling, recycling over reuse etc (ibid).

The study defines three focus area where regulatory instruments can push incentives towards waste valorisation and creating favourable condition for symbiotic activities[50]:

- Key area 1: **Collection of waste streams**: lack of legislation that would allow the collection and pre-treatment of homogenous waste streams. Without specific legislation many waste streams end up as mixed waste where costs for high

[49] See Technopolis Group, Wuppertal Institute, Thinkstep, Fraunhofer ISI (2016): Regulatory barriers to the circular economy. Lessons from ten case studies.

[50] Ibid, Technopolis Group et al, 2016

quality recycling are higher than achievable revenues for recycled materials (e.g. in the field of plastic packaging).

- Key area 2: **Uptake of secondary resources**: legislative changes that allow flexibilities for using recycled materials in production processes. Health and consumer protection legislation may in some cases pose restrictions to secondary materials, associated with risks of cross-contamination.
- Key area 3: **Design for reuse, repair or recycling**: design issues are already for quite some time high on the agenda but concrete and enforceable product requirements are still lacking.

In December 2015, the European Commission published the Circular Economy Action Plan[51], as part of a package also containing four proposals amending several legal acts, with a view to making them more ambitious[52] with a stronger emphasis on circularity and development of secondary markets for materials.

The four legislative proposals aim to address some of the concerns mentioned above. They introduce new waste-management targets regarding reuse, recycling and landfilling, to enhance waste prevention and extended producer responsibility, and streamline definitions, reporting obligations and calculation methods for the targets. The proposals also amend Articles 5 and 6 of the Waste Framework Directive, dealing with by-products and 'End of Waste' respectively, with a view to clarifying issues around these concepts. At the time of writing of this report (January 2018), the informal agreement reached between the European Parliament (EP) and the Council of the EU is awaiting formal approval by both co-legislators.

The January 2017 Circular Economy Action Plan progress report of the Commission (COM(2017) 33 final), shows that the Commission has started acting upon some of the other regulatory challenges (including by launching a new legislation for completing the single market for fertilisers as secondary raw materials which has generated some concerns regarding the recognition of current IS practices in the fertiliser sector). Furthermore, the EC has reconfirmed the importance of eco-design and put forward a new 2016-2019 Working Plan for actions in the field of Ecodesign, as part of the Clean Energy for All Europeans package (see EC, 2017)[53].

The survey with IS facilitators highlighted key areas where policies would help in facilitating IS transactions, which confirm the need to speed up the implementation of the EU-level actions presented above, but also the importance of national-level actions. The facilitators' recommendations concerns include, firstly, the revision of waste regulation, then introduction of economic instruments such as taxes and tax breaks and then direct support for facilitation. Moreover, when asked specifically what regulations need improvement to support IS, the setting of ambitious targets for recycling and landfilling were seen as very important by 27 % of the respondents. The majority (73 %) have mentioned the clarification of ''End of Waste'' criteria as important or very important.

The results of the stakeholders consultation show that **adequate waste regulation is crucial in promoting IS.** The current Waste Framework Directive and its implementation across MS are, in need of streamlining and harmonisation if they are to support IS in practice. In particular, as shown above, **definition of waste and by-products and the 'End of Waste' criteria** have been regarded as some of the top barriers in fulfilling IS synergies. However, interviewees also recognise the role of waste policies as important incentives because they "*can create or stimulate a more viable economic model for symbiosis, by creating value for products or materials that currently*

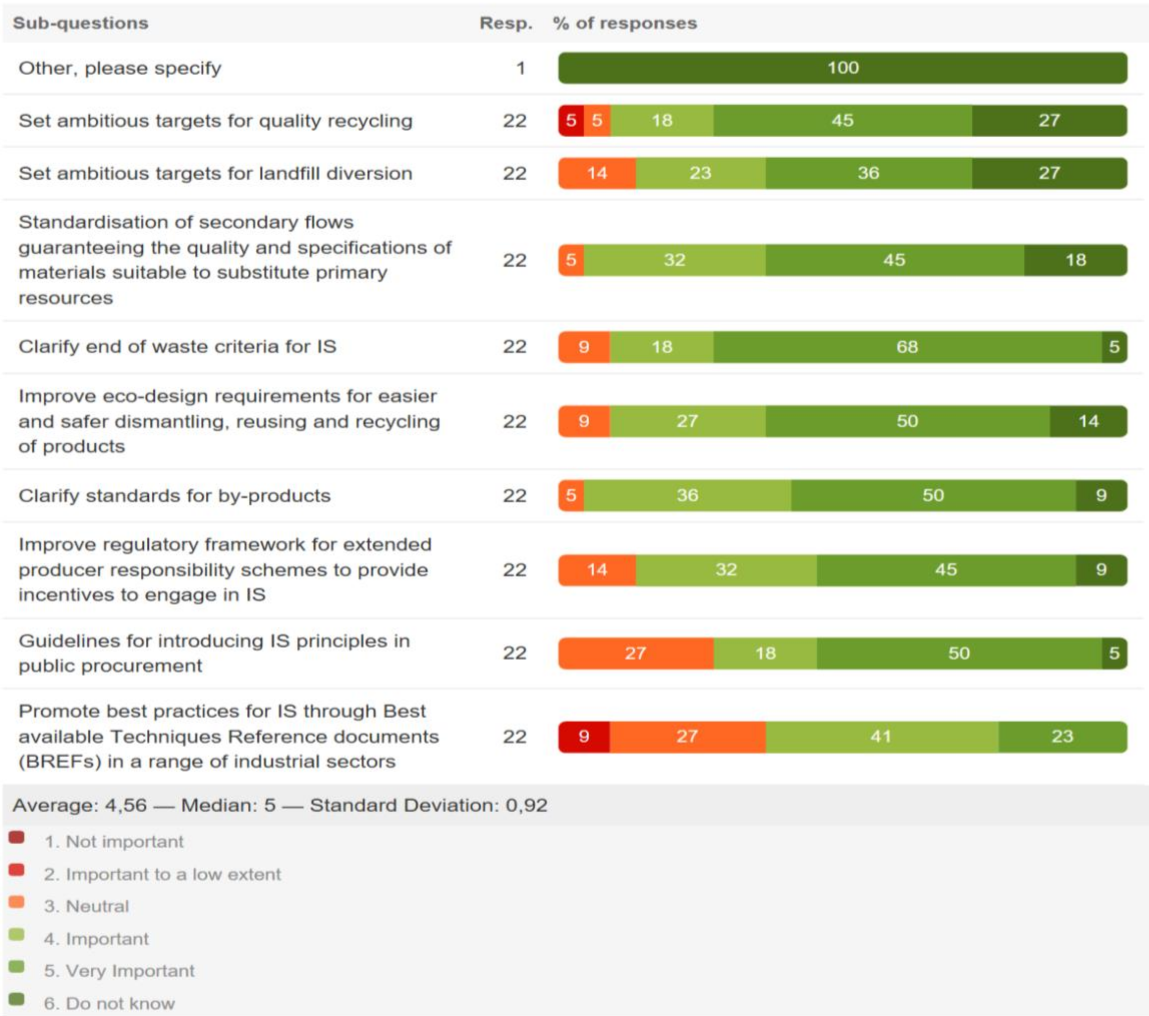
[51] See European Commission, (2015): Communication on Closing the loop - An EU action plan for the Circular Economy COM/2015/0614 final

[52] Including Waste Framework Directive, Landfill Directive, Packaging Directive, and Directives on end-of-life of vehicles, batteries and accumulators, and waste electrical and electronic equipment

[53] European Commission, 2017: Circular Economy Action Plan Implementation Report (COM(2017) 33 final), http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

do not have value in the eyes of the majority of the companies". Currently, however, most companies still see waste as a burden and not a resource.

Figure 31 EU Regulations that need improvement based on survey replies



Source: authors based on survey with IS faciliators, n=22; multiple-choice question.

The 2016 study on regulatory barriers to the circular economy (Technopolis Group, 2016) found that the implementation of the Waste Framework Directive differs across the EU MS, including in the case of the classification of a material as being a "product" or a "waste". A result of this situation is the fact that, in case of cross-border activities, or in some cases even cross-regional activities, an activity with the same material may have to comply with both product and waste legislation, if the material is considered a (by-)product in one country/region and a waste in another. This in practice means the administrative burden (in time and money) of both legislative systems apply to the activity. Needless to say this influences the potential profitability of cross-border IS activities and subsequently companies' decisions of whether or not to engage in them. This is why a harmonised approach to implementing the waste framework legislation was thought to be crucial.

Furthermore, the varying interpretation by MS of the Waste Framework Directive with regards to by-products creates regulatory uncertainty regarding the legality of using certain by-products, which increases the perceived risk by companies of engaging in IS transactions. Although the EC has provided guidelines to establish when a material should be considered a (by-)product or waste, interpretation across MS varies substantially. Interviewees' perception is that the directive is transposed in a flawed and unclear way in some countries, such as Romania, which makes the rules hard to understand by companies and municipalities. In other countries, such as France and Belgium, the definition of waste can be different even between different regions, as environmental protection agencies have their own interpretation. Some MS have opted for not transposing the concept of 'by-product' or relying on previous regional legislation of by-products (e.g. Catalonia in Spain). The clarification of the concepts of by-products and end of wate status, as included in the on-going revision of the Waste Framework Directive, better clarified concepts may indeed help to promote IS if it leads to more harmonised implementation across MS.

Another potential flaw highlighted during the interviews is that the current interpretation of the concept of by-product has mostly been applied to secondary materials with a well-established market (although the WFD does not establish this as requirement for 'by-products' in art.5). This is also motivated by the fact that in some countries the administrative procedure for the application for 'by-product' status is subjected to a relative high cost. .However, there are instances where industrial by-products do not have a market value as they are of inferior quality relative to primary raw materials, but their use can actually be beneficial to the parties involved. An example is the liquid waste generated from acidic baths of metal surface treatment processes. The used bath is rich in ferrous chloride. On the other hand, ferrous chloride is used as coagulant in the treatment of industrial waste water and therefore it could substitute primary coagulants. The quality is inferior to the primary material,_less concentrated,_ and therefore the market value reduced or zero. However, if the metal company is willing to give it for free, there may be potential benefits for both parties involved. Although, a strict interpretation of the WFD would classify this as a 'by-product', as it does not need to undergo any valorisation process as such, under current WFD interpretation made by some MSs, this would be considered a waste rather than a by-product. Even when there is a correct interpretation, in cases where the administrative costs and burden associated to a 'by-product' are high, companies may still prefer to treat this as a waste. Clarifying the interpretation of the concept of by-product and streamlining its administrative procedure, for secondary resources with low or no market value, could promote more efficient use of resources.

Better data collection and monitoring of types of resources transactioned as by-products and their volumes would contribute to better understanding of the potential.

Simllar challenges apply to the application of 'end-of-waste' criteria. The main difference with the definition of by-product is that where by-products did not become waste, here the material has become waste but after a recovery operation it can be considered a non-waste if it fulfills a number of criteria. Again here uncertainty in the application of regulation and interpretation of the criteria of when something that was a waste ceases to be a waste creates important obstacles to IS transactions. At the EU level EoW criteria have been established for three waste streams: 1) iron, steel and aluminium scrap; 2) glass cullet and 3) copper scrap. This is of direct application to all MS and thus implementation should be harmonised. MS can also define EoW criteria for other waste streams. Some MS have done this extensively (e.g. the UK) while other countries have not defined any EoW criteria. Where it has been applied, the scope and legal application of EoW varies leading to uncertainty involving transactions of waste/non-waste.

Some industrial associations have lobbied for the application of end-of-waste criteria for certain materials important within their sector. Interviewees have also noted that meeting 'End of Waste' criteria requires substantial effort (and in some cases high costs), which is unlikely to be undertaken by individual firms.

As in the case of by-products, better data and monitoring of EoW across MS through, for example, a register of EoW which would be available through the EC could contribute to better harmonisation and understanding of potential challenges to IS transactions across borders. It would also contribute to understanding areas with potential for IS, as it would provide information about types of waste that could be reinstituted as secondary resources. This could be done through an online platform at EU level to help users review materials that have obtained the EoW status in other MS.

Restrictions imposed on waste transport across MS and regional borders are linked to significant administrative burden. Therefore companies perceive a risk that the material they transport will be considered a waste by authorities at some point during the transport, invoking the administrative costs.

The lack of clarity in the regulation has also been reported as a barrier for obtaining private or bank financing for acquiring technology to process the IS match, as companies and banks often do not know if the IS setup would be within of the law, as also confirmed by an EIB report (2015). There therefore needs to be more clarity and consistency in decisions made that a material or substance part of an industrial process is a by-product, in order to encourage companies to invest in IS.

The interviews with IS facilitators suggest that a substantial part of the time of IS practitioners is devoted to finding clarification and exemptions to the application of waste regulation. Facilitators such as NISP UK, or SMILE Ireland have been facilitating discussions with the regulators to obtain exceptions or clarify the regime that applies for some of the identified potential synergies. As a follow-up, the regulators in the UK and Ireland were in most cases able to find ways to support the IS process in the identified cases. Nevertheless, in other countries such as Hungary and Romania the regulators are very strict or lack technical capacity to tackle the issue and there are low chances of obtaining exceptions or permissions for complex synergies. The issue of risk linked to ambiguities of the legislative framework affect not only firms but also civil servants, which may lack technical expertise to evaluate end-of-waste criteria. Flexibility in legislative implementation and enforcement requires not only a good understanding of legislation and technical capability to ensure implementation and enforcement but also evaluation of exemptions, which is challenging for businesses and civil servants alike.

Some countries have found different solutions for easing the companies' burden in dealing with cases where the definition of waste is problematic. For instance, the UK introduced the Waste Protocols Project (WPP), a regulatory instrument, as a response to dealing with uncertainties regarding the EU's waste definition. This was considered a way to avoid some materials were going to landfill despite their reuse potential. The protocols were developed by WRAP – the UK's Waste and Resources Action Programme – together with the UK Environmental Protection Agency and published in 2014 as a framework to inform producers and safeguars consumers, on what technical aspects and quality criteria the material must fulfil in order to be exempt from being considered a waste[54].

The **Green Deals** example was given from the Netherlands as a method for coordinating the finding of solutions to regulatory barriers experienced by companies trying to introduce new sustainable products, technologies or services to the market. The Dutch central government works with a group of stakeholders (interest groups, companies, researchers) in an open procedure to reach an agreement to solve the barriers encountered in bringing to market the specific new sustainable innovation. From 2011 and 2014, the Dutch government reached agreement on 176 Green Deals, with the involvement of 1,090 participants in their design.[55] An example of an international green deal was launched by the Netherlands, Flanders, France and the UK, under the concept of "North Sea resources roundabout", with the intention to reduce the regulatory differences caused by varying national implementations of EU rules, so as to facilitate cross-border movement of materials.[56]

Following up on this model, the European Commission has launched a similar initiative under the name of "**Innovation Deals**", which aim to resolve perceived regulatory barriers to innovation under certain conditions and allows groups of companies to request a review of specific regulations.

Further improvements that the interviewees mentioned as important relate to the need to define stricter terms for the activities of the productive sector in terms of their use of resources and impact on the environment. The need for landfill bans has been re-

[54] WRAP, (2015): The Quality Protocols, http://www.wrapcymru.org.uk/content/quality-protocols
[55] See more details here: http://www.greendeals.nl/english/green-deal-approach/
[56] See Netherlands Circulair!, 2016: The launch of the North Sea Resources Roundabout, https://www.circulairondernemen.nl/cases/the-launch-of-the-north-sea-resources-roundabout

iterated, as well as targets for zero-waste, resource efficiency and waste prevention and reuse of resources (materials or products). The current status of the system is considered 'very much in favour of waste creation', and not conducive to waste prevention. Moreover, a ban to send unsorted waste to incineration was seen as important.

Standardisation/homogenisation of the secondary materials is key for the success of an IS transaction. Waste streams and process residuals may require to be homogenised/standardised in order to guarantee the quality and specifications and to become viable alternatives to virgin raw materials, creating confidence in the quality and performance of the material to drive the demand of secondary materials. This may reduce uncertainty and technical barriers to transactions of secondary raw materials. The cement sector, for example, generally works in partnership with waste/recycling companies that help in providing a homogeneous alternative fuel, as variations in the temperature of the kiln due to changes in bio-chemical composition of fuel could negatively affect the quality of the final product. Also other sectors, such as automotive, pharmaceutical or construction that have to comply with strict standards in terms of product performance or security may be reluctant to use PRs that are not adequately standardised or homogenised. Types of by-products where standards were thought important include not only slag, but also other materials such as organics, dust, slurry and other solids (Technopolis Group et al, 2016). For some sectors and materials, proposals have been developed to create some sort of certification system for secondary materials to guarantee their composition/characteristics. An example of this the work of the standardisation technical committee CEN/TC 366 on "materials from end of life tyres".

Moreover, stakeholder discussions during the focus group and interviews suggested that the *concept itself of IS cooperation / IS synergy should be standardised*, so as to facilitate a wider take-up. Stakeholders believe that this standardisation process shouldn't be a technical standard tool, but rather a process report or guidance document for regional or national authorities undertaking IS, or other organisations involved as facilitators. This could take the shape of a voluntary protocol such as the EU Construction and Demolition Waste Protocol – which defines guidelines and best practices for C&D waste management or the Circular Economy Standard produced by the BSI[57] – a guide with specific elements on how to integrate circular thinking into any company. In the case of IS, the purpose of standardisation would be to clarify and harmonise vocabulary, IS best practice facilitation and processes, promote best practices and build on existing knowledge of IS opportunities to facilitate replication. In the stakeholders' opinion, the guide would describe roles and expertise required for facilitating IS and would be designed together with multiple stakeholders. Concrete steps are taken in this respect, as the first CEN (European Committee for Standardisation) Workshop Agreement takes place on Febuary 21st 2018.

Eco-design had been drawing big attention in the circular economy agenda. What this could mean for the IS models has not been discussed widely. The stakeholders consulted in this study tend to recognise that eco-design also plays an important role in the IS discussion. The links between IS and eco-design are in two areas: 1) waste prevention and 2) recovery of parts and materials at the EOL stage of products, which would facilitate IS activity. IS could help to identify alternatives to primary materials at the design stage, preventing the production of waste and promoting re-circulation of materials. Also importantly, product recyclability and even the possibility of using disassembled components in other production systems, can benefit from symbiotic activities. Therefore, the importance of eco-design is seen both from the higher objective of waste prevention, and, as discussed at the interviews and focus group, for promoting the reuse and reutilisation of secondary materials at later stages. Eco-design thus should be part of the core principles in IS models.

[57] See BSI, 2017, British Standard for the 'circular economy' launched, https://www.bsigroup.com/en-GB/about-bsi/media-centre/press-releases/2017/june/Ground-breaking-British-Standard-for-the-circular-economy-launched-/

In addition to eco-design there is additional value from industrial symbiosis as an introduction to several other circular economy/industrial ecology tools such as cleaner production, remanufacturing, carbon accounting, etc. The focus of facilitated industrial symbiosis on wide, inclusive, cross-sector enagement gives possibilities for introducing these other concepts/tools.

7.2.2.Economic instruments

A number of economic and fiscal instruments can create favourable conditions for the companies to engage in IS. The example of such instruments include the following:

- Policies increasing the cost of landfilling, such as landfill taxes
- Resource taxes (e.g. embedded carbon tax), which a focus on internalising costs linked to extraction and processing of virgin raw materials
- Tax incentives for the use of secondary resources and repair and maintenance activities (e.g. VAT reduction)
- EPR schemes with differentiated charges

The **instrumental role of landfill taxes** and bans in promoting IS has been critical especially in resource intensive industries such as construction (Wilts et al., 2015; FISSAC project, 2016). A review of policies that support industrial symbiosis have found landfill taxes to be highly effective – looking at cases such as Denmark, Switzerland and UK (Costa et al, 2010)[58]. For instance, the case of Denmark is a long-standing policy for deterring waste from landfill, tracing back to 1987 with an increasing incineration and landfill tax coupled with landfill bans introduced in 1997. In Switzerland, taxes and a ban on all combustible wastes were introduced in 2001 and 2002. The UK introduced a landfill tax in 1996, but this only became effective in 1999, as it was coupled with an increasing yearly rate (tax escalator). This policy has been replicated in several countries by now. The UK introduced further restrictions to landfilling of liquid wastes and tires in 2006 (ibid). At the same time there has been an increase of waste recovery practice across a number of EU countries. Eurostat shows that the share of recovery in total waste treatment in EU rose from 45.4 % in 2004 to 51.1 % by 2014[59] and this seems to be due to either landfilling bans or a combination of landfill tax and banning[60]. Interviews with emerging facilitated networks in east European countries, such as Hungary and Romania, have also pointed to the low price of landfilling as a barrier for the companies to pursue more resource efficient options and engage in IS networks. In addition, the survey with IS facilitators seems to confirm that making landfilling costlier and introducing landfill banning supports IS, although other measures are also seen as highly important.

Higher **resource taxes** have been increasingly highlighted as important instruments for setting adequate framework conditions for circular economy and boosting resource efficiency. EEA (2016) concludes that taxing energy and carbon through resource taxes offers opportunities to improve material resource efficiency. However, although some examples exists of resource taxes applied to specific resources (e.g. aggregates), they have not been widely and broadly adopted in the EU. Furthermore, there is no sign of an increase in the share of resource taxes in environmental taxes over recent years, despite an increasing focus on material resources in EU policy.[61] High political sensitivity of any tax system reforms has been a major barrier to this as the EC (2016) study

[58] Costa, i., Massard, g. and Agarwal, a., 2010. Waste management policies for industrial symbiosis development: case studies in european countries. Available from openair@rgu. [online]. Available from: http://openair.rgu.ac.uk

[59] http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics

[60] https://www.eea.europa.eu/data-and-maps/indicators/waste-recycling-1/assessment , however, these are municipal waste statistics

[61] https://www.eea.europa.eu/airs/2016/resource-efficiency-and-low-carbon-economy/environmental-and-labour-taxation

shows[62]. As dicussed earlier, the relatively low cost of primary resources compared to secondary reources has been seen as a key obstacle for initiating symbiotic activities, therefore higher taxes could drive the prices up, making use of secondary materials more competititive. Stakeholders consulted during the study largely agree with the idea that progressing the resource tax policies in the EU would ensure the higher diffusion of symbotic activities and wider use of secondary materials.

Other tax incentives are seen as another component of the framework conditions that could positively benefit circular activities in general. As an examples, a number of EU Member States have made efforts to reduce VAT on repair services and second hand goods[63] with the objective of reducing waste and promote local jobs. Using a similar logic, tax incentive instruments potentially can also be helpful in promoting IS activities and business models. Tax breaks for the use of secondary materials could promote secondary markets in Europe.

Imposing **Extended Producer Responsibility (EPR)** schemes has already demonstrated impact in promoting waste recycling and diversion of large amounts of waste from landfilling in many countries, as well as, to a lesser extent, increasing remanufacturing activities. The focus of EPR has been largely on specific sets of products (or packaging) and post-use handling of these products. The majority of the consulted stakeholders see EPR as a instrument that can be extended to a wider range of products and where IS could play a role by facilitating synergies across companies to meet the EPR requirements and maximise high value recovery of parts, components and materials.

7.2.3. Supply chain approaches

The analysis of existing successful examples of IS in Europe also reveal the importance of promoting IS through supply chain approaches. Supply chain approaches tradionally work across one single supply chain minimising wastage and increasing resource efficiency. However, introducing IS perspective could create incentives to foster cross-supply chain collaboration, where resources are optimised across a number of supply chains to maximise gains. In fact, the review of evidence suggest that an important driver for self-organised activity has been pressure exercised from the supply chain to improve environmental performance leading to collective solutions through industrial symbiosis approaches. Especially in the case of SMEs, pressure from the supply chain can act as a catalyst of change to improve efficiency and environmental performance. In the case of the tannery cluster in Italy, supply chain pressure drove collective environmental solutions. In Sagunto (Spain) pressure from the automotive industry also drove upstream changes and led to exploitation of IS opportunities as a way to reduce environmental impact (Domenech and Davies, 2011).

Supply chain approaches are generally motivated by 'social licence to operate' and affected by transparency and disclosure policies. Setting the right framework conditions for greening supply chains may, indirectly, support industrial symbiosis, by identifying opportunities to enhance resource efficiency along the supply chain but also importantly across other supply chains, as outlets for waste streams from one supply chain may be suitable feedstock for another supply chain. Working across different sectors and supply chains is indeed one of the key areas of innovation of IS.

7.2.4.Green public procurement (GPP) and building rating schemes

GPP can also act as a driver for IS activity by introducing and prescribing IS practices in tenderings. An example could be the promotion of secondary materials in the provision of infrastructures or services or the introduction of reutilisation rate targets in public projects. Examples of best practices can be found especially in the area of civil

62 EC, 2016, Study on assessing the environmental fiscal reform potential for the EU-28(http://ec.europa.eu/environment/integration/green_semester/pdf/Eunomia%20EFR%20Final%20Report%20MAIN%20REPORT.pdf).

63 http://www.rreuse.org/wp-content/uploads/RREUSE-position-on-VAT-2017-Final-website_1.pdf

engineering and construction works. In Bulgaria, contractors are required to use recycled building materials. In the UK, tendering processes may set guidelines for waste diversion from landfill or there are examples of voluntary agreements in the Netherlands that apply to procurement procedures related to construction and demolition. Use of recycled concrete in road works or recycled aggregates instead of primary aggregate are also examples of good practice in procurement and tendering processes.[64]

A niche application of industrial symbiosis is being utilised in the UK by bringing together construction companies with utilities via the Major Infrastructure Resource Optimisation Group established as a spin off from NISP, and launched based on a private sector initiative[65]. The Group was founded in 2013, aiming to introduce GPP principles and circular economy thinking into major infrastructure operators' procurement practices. The goal is to shift the insfrastructure operators' purchasing habits by acting from the early-design and feasibility stages of projects, which would ensure the achievement of larger-scale resource efficiency and maximise value and durability of products, components and materials used in the infrastructure projects.[66]

7.3. The creation of an EU platform to support industrial symbiosis

Among the objectives of this study was to assess whether the creation of an EU level platform or EU coordination mechanism could help to support IS implementation, what could be the structure and functions of this platform and identification of possible options and their feasibility. The purpose of this chapter is, thus, to assess the needs and options for EU support in scaling up and promoting IS initiatives across Europe. Based on the stakeholders' consultation, including interviews, survey and focus groups, this chapter summarises key ideas and initial feasibility of EU coordination to promote IS, and identifies appropriate instruments to support it.

The scope of the analysis has been broad aiming at identifying current needs and the level of coordination at different geographical scales. The analysis has focused on three main interrelated areas:

- Is there a need for collaboration between coordination nodes at different levels (local, regional, national, supranational)
- Could an EU level coordination platform or trading platform address cross-boundary synergies?
- What existing structures could provide different services for an EU level coordination platform?

An EU platform for facilitating industrial symbiosis can take many forms; hence the aim of the study has been to **explore, in consultation with key stakeholders, different options and formats**, including some reflection of advantages and disadvantages of different options.

This study has investigated different aspects for each identified option such as:

- stakeholder positions towards the creation of an EU-level platform and towards different options;
- identification of potential services, structure and organisational requirements, information management options (including types of digital platforms);
- an assessment of strengths and weaknesses of the identified options;

[64] EC (2017). EU Construction and Demolition waste protocol, available online at https://ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en

[65] see http://www.aecom.com/projects/circular-economy-action-major-infrastructure-resources-optimisation-group-mi-rog/

[66] MI-ROG, 2016: Embedding circular economy principles into infrastructure operator procurement activities. A white paper. http://www.aecom.com/content/wp-content/uploads/2016/08/160220UKI_MI-ROG_White-paper.pdf

- potential differences across industries or focus on specific industrial value chains.

The following sub-sections present the findings of the consultation and analyse options assessment for further EU level support.

7.3.1.Needs assessment for the creation of an EU platform for IS coordination

The needs for EU support to IS coordination was assessed through: 1) survey to facilitators and 2) discussions with businesses, policy-makers and companies as part of focus group discussions and interviews. Results from the consultation process see **value added of EU support in three main areas: 1) creating adequate framework conditions for IS; 2) promoting the dissemination of knowledge, best practices and technologies and 3) contributing to capacity building of different stakeholders.** Findings suggest that stakeholders largely see promotion of synergies as something that could be done more effectively at the local and regional level. In this section, the focus will be on knowledge and capacity building. The role of setting adequate framework conditions will be explored in more detail in the policy recommendation section.

Figure 32 IS facilitators' views on the needs for a EU platform for IS

Source: authors based on survey with IS faciliators, n=22; multiple-choice question.

As shown in Figure 32,**Error! Reference source not found.** summarising results from the survey, actions such as a) knowledge building, good practice sharing, creation of a knowledge base and b) capacity building for policy-makers to develop IS friendly policies have been the options ranked as very important by 50% and 45% of IS facilitators respectively.

Knowledge building has been defined in a broad sense and covers enhanced understanding of resource flows, identification of IS synergies, dissemination of case studies, development and dissemination of adequate technologies that enable the transformation of waste as a resource (e.g. technologies for removing pollutants from secondary materials; segregation of material components; testing and homogenisation) and skills. Most stakeholders consulted see knowledge building as an important feature of an EU platform, for policy-makers, IS facilitators and business organisations. Main services or options for the platform's functions discussed included the collection of data and showcasing of information on, for example, types of recycling technologies available in Europe, IS potential of specific materials, sectors and value chains, as well as lists of repurposers and recyclers who can manage specific waste streams using BATs. Identifying market potential for specific materials can play an important role for different stakeholders: it would help policy-makers identify policy rationale and focus, as well as support IS facilitators with identifying potential synergies while providing guidance to individual companies and industry associations to identify key opportunities. The European Resource Efficiency Knowledge Centre[67] (ERIK) is an initiative funded under COSME which aims to develop a knowledge base on resource efficiency, including good practices or technologies. More links could potentially be created between ERIK and industrial symbiosis. Alternatively, stakeholders also commented on the possible links between IS and the newly created CE platform at the EU level.

Moreover, **capacity building** for policy-makers and IS facilitators is another critical area where support from the EU could be transformative. Capacity building is required to turn knowledge into actionable measures and therefore is necessarily linked to 'knowledge building'. The sudy has identified capacity gaps for policy-makers and facilitators in countries that are starting to develop IS cooperation. For policy-makers main gaps identified include lack of technical capability to evaluate environmental risks and benefits associated to synergies, capacity to adapt and implement complex regulation (e.g. 'End of Waste' criteria) and ability to negotiate with industrial actors. Also, importantly, several interviewees argued that, due to the nature of the IS process and the holistic approach it requires in its implementation, it challenges current silo thinking and distribution of responsibilities and traditional segmentation of areas of policy intervention. IS barriers may span across sectors, policy areas and departmental responsibilities. Overcoming these barriers requires significant coordination across national ministries, regional bodies and aligment of policy action across areas, which may not yet be a common practice in many EU MS, especially in central and eastern European states. Low technical capacity is also perceived as critical as it imposes an important barrier to developing the appropriate regulations and, more importantly, implementing complex instruments while maintaining a flexible approach to, for example, explore the opportunities to transform waste into a by-product or resource. Stakeholders interviewed emphasised the need to work with national and regional policy-makers to provide guidance and capacity-building for IS and transposition of critical instruments such as 'End of Waste' criteria.

The interviews highlighted challenges related to flexible implementation and interpretation of waste regulation where coaching schemes for regional/national policy-makers and civil servants could enhance application of instruments such as 'end-of-waste' criteria. Interviewees also stressed the untapped potential to other instruments for the promotion of IS such as licensing of IPPC activities, by promoting adoption of IS principles (this will be discussed in more detail as part of the policy recommendations). However, capacity building among civil servants and support from policy-makers was considered key to make this happen. IPPC activity covers a large part of industrial resources and waste, but its application is complex and requires technical capacity to identify and negotiate options, understanding of the opportunities derived from: a) application of BATs; b) raw material substitution and fuel alternatives; c) comprehensive

[67] http://www.resourceefficient.eu/

knowledge of the industrial ecosystem of a regions (analysis of resource flows within a region). This, therefore, relies on better availability and quality of data, understanding of IS principles, expert technical capability and support through databases of best practices and successful IS projects.

For facilitators, lack of capcity affects the ability to identify IS opportunities and engage with key stakeholders. Also, in many cases, resources of facilitators are very limited and the time-span of projects too short, resulting in difficulties to set up appropriate infrastructures and build trust and cooperation practices between industrial actors, policy-makers/civil servants and facilitators. Capacity building has been identified as critical especially in the earlier phases of IS, including setting-up of the network. Capacity building includes training of experts but also creation of a knowledge base that allows for a comprehensive overview of resource flows in the territory combined with understanding of opportunities to transform waste into resources. Other areas where lack of capacity has been identified as an issue include technical and legal/regulatory issues, depending on the specific needs of regions and MS. As in the case of policy-makers, skills surrounding negotiation with industrial partners and ability to understand business drivers combined with an in-depth knowledge of different sectors of activities have been highlighted as extremely important in improving the performance of facilitators.

A low cost way of having the critical mass of expertise available may come from taking the approach of 're-purposing' existing business support professionals through training in applying industrial symbiosis, which would reduce the need to recruit additional human resources. Related to both knowledge and capacity building, the consultation process also pointed to opportunities derived from the **collaboration and exchange of experiences across regions and IS networks.** Peer to peer advice and dissemination of good practices (including how to address barriers) has been highlighted as very important to promote IS including identification of cross-boundary opportunities. Collaboration in this area could happen between IS facilitators but also across policy-makers and civil servants involved in promotion of IS activity. Similarly, peer to peer exchange of experience with industrial symbiosis transactions and more general best practice has been an important factor (but typically not captured in terms of outputs) in facilitated IS networks.

There was agreement among stakeholders that IS initiatives across Europe should communicate better with each other and would benefit from better coordination to avoid repetition of efforts and enhance learning opportunities. This is something that also extends to EU-funded projects in the area of IS, be it under INTERREG (e.g. TRIS, SYMBI projects), Horizon 2020 programmes or other funds, where little coordination has led, for example, to the development of different online platforms with different architectures and structures where coordination and potential integration could have been extremely useful. Also the lack of a harmonised assessment method (now part of the subject of a CWA) for IS has constrained the understanding of the impact of implemented actions.

The **direct financial support** to companies' R&D activities for IS is another area that has been ranked as among the most important needs for EU intervention by IS facilitators. Beyond simple synergies, that require little or no modification of waste streams into products, many synergies require clean-up or homogeneisation for optimised potential. This may require actions from feasibility studies to testing to development of new infrastructures or technologies. In this cases, financial support in the first stages of development may be critical. Moreover, stakeholders highlighted the need to address the scale-up phase of the IS facilitated networks, which is a gap in the current EU and national funding frameworks in the majority of EU countries.

The consultation process also highlighted the role of PPPs in some areas of industrial symbiosis where the market incentives are limited. An example of this is recovery of food waste, where PPPs could drive more efficient collection and utilisation of food waste. The study has also revealed the important role played by PPPs in self-organised activity by supporting private investement and collaboraton through development of enabling infrastructures for IS implementation.

7.3.2.Options assessment for an EU platform

From the stakeholders' consultation, three possible functions for EU IS coordination emerged: 1) the creation of a 'platform of platforms' that would integrate, harmonise and provide support to regional/national initiatives; 2) the creation of a trading platform at the EU level to foster cross-boundary synergies and 3) the creation of a centre of excellence for IS.

In any case, and as emphasised above, stakeholders stressed the need of coordination and sychronisation with the European Circular Economy Platform and other similar initiatives, such as the European Resource Efficiency Knowledge Centre (ERIK).

Option 1: Platform of Platforms for IS

The first option explored was the creation of a platform of platform that would provide a forum for the exchange of best practices and knowledge across regional networks. The platform's members would be regional and national programmes across different MS in the EU but potentially also policy-makers. A similar initiative engaging coordination bodies was attempted by the creation of EUR-ISA in 2014 (http://eur-isa.org). EUR-ISA generated some interest across IS programmes but the activity has been terminated due to the lack of financial support and the fact that regional programmes have worked for short periods of time and with little continuity with the exception of a number of long-standing networks.

An EU-level platform of platforms could well adopt a similar structure to EUR-ISA or even revitalise the EUR-ISA initiative. Figure 33 below summarises main purposes and activity of EUR-ISA. However, adding a policy-makers interface would also address the lack of capacity of national, regional and local authorities to promote IS in their territories.

The option of a 'platform of platforms' as discussed during the stakeholder consultation would focus on enhancing the knowledge base for industrial symbiosis and facilitating knowledge sharing. The discussion has also emphasised that the main audience for the platform of platforms would be IS practitioneers and policy-makers, while companies would engage directly with the relevant regional networks.

The main activities of the platform of platforms could be summarised as follows:

For facilitators:

- ✓ Provision of peer-to-peer support for identification and management of synergies
- ✓ Dissemination of best practices and knowledge across IS initiatives
- ✓ Creation a forum for IS practitioners to discuss more complex synergies
- ✓ Provide opportunities for periodical interactions of IS practitioneers through the organisation of events, symposia and related activities

For policy-makers:

- ✓ Discussion and exchange of best practices and examples of successful synergies between regions
- ✓ Contribute to generate mission oriented knowledge about best practices in policy making and adequate framework conditions
- ✓ Creation of awareness of opportunities derived of IS
- ✓ Identification of key barriers to IS implementation and discussion of areas of intervention of overcome barriers
- ✓ Provision of a peer-to-peer support to policy implementation

Figure 33 EUR-ISA purpose and activities

The association has as non-profit purpose:

- To establish a framework to provide the European Commission with a single point of contact acting in the interests of multiple industrial symbiosis networks across all EU Member States
- To help demonstrate to the European Commission the potential contribution of industrial symbiosis to resource efficiency and the circular economy
- To help enable widespread implementation across Member States of proven industrial symbiosis models from EUR-ISA members
- To identify enablers and barriers for to the European Commission to enable action to be taken to improve the implementation of industrial symbiosis

In order to achieve the above mentioned purpose, the Association may conduct the following activities, for the benefit of the members and third parties:

- Research, analyse and supply information relating to enablers and barriers for industrial symbiosis
- Act as a representative body on industrial symbiosis and circular economy with the European Commission
- Providing facilities for EUR-ISA members or third parties, by providing meeting rooms including virtual office and business centre services for short and long term periods
- Hold meetings, conferences and seminars and promotional activities, in support of EUR-ISA
- Act as a financial accountable body for any EU or other organisation funding programmes
- Undertake non-commercial activities to achieve the above objectives

The Association may also carry out all operations and conduct all activities, both in Belgium and abroad, which directly or indirectly increase or promote its purpose or objectives.

Option 2: Trading platform

The second option discussed during the stakeholder consultation was the creation of a trading platform for cross-boundary synergies at the EU level. The discussion of the potential development of an EU-level trading platform raised some **doubts whether such a platform would be feasible and effective. In general, local and regional levels are seen as better suited to promote IS synergies.** Most of the stakeholders consider that synergies can be better coordinated at the regional level or perhaps through the 'platform of platforms' rather than through solely a EU trading platform. The main concerns raised revolved around the ownership and management of the platform (who would own it and who would manage it) and its actual viability, as cross-boundary opportunities are currently facing important barriers related to limitations imposed by regulations related to transport of waste and lack of harmonisation of end-of-waste status across country/political boundaries. These barriers need to be addressed before any IS cross-boundary coordination can effectively be implemented. It was also noted that neither companies nor facilitators would intituively address the EU for cross-boundary IS synergies. There were also issues related to the confidentiality of data and its commercial character, where the platform at the EU level was seen to create some potential friction. Table 19 summarises key discussions.

Table 19 Key discussion points on an EU-level trading platform feasibility

Structure	Potential functions	Challenges
EU coordination with inputs from industries and regional facilitators	Identification of synergies across boundaries Connection between key players with potential matches Facilitation from inception to development? Support for overcoming regulatory, technical and other barriers?	Lack of clarity around who would manage the trading system at the EU level Problems surrounding confidentiality of the data Lack of clarity of responsibility issues derived from transport of waste/by-products across boundaries

Source: authors, elaborated based on stakeholder discussions

In summary, a web-trading platform was thought not to be an area where a public body, such as the European Commission, should intervene with direct support. For these reasons, most stakeholders consulted thought this option was unfeasible. However, the creation of a web architecture, harmonised across regional initiatives, was seen an area where the EU could add value, overcoming current problem of lack of integration of existing IS web tools.

Option 3: Centre of excellence for IS

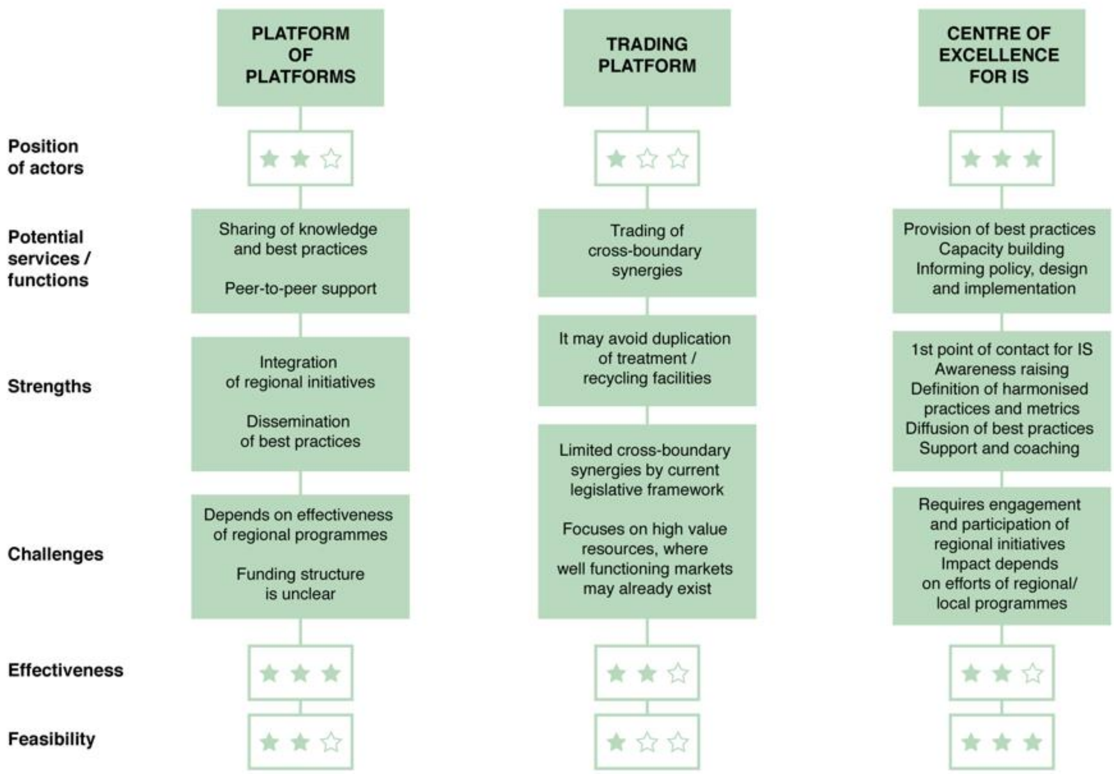
Option 3 builds on option 1, but adds a focus on capacity building that was the other key area identified by key stakeholders as critical to promote further uptake of IS solutions. Therefore, the centre of excellence would not only constitute a forum for the discussion and exchange of knowledge but would actively contribute to: 1) enhance the knowledge base for industrial symbiosis in Europe through research and systematic data gathering and analysis; 2) develop capacity in the area of IS, targeted at IS practioneers and policy-makers to promote adoption of best practices and enhance facilitation impact and policy implementation through tailored coaching and skill development problems; 3) promote bottom-up uptake of industrial symbiosis through self-regulation and adherence to common approaches in the reporting of results of symbiotic industrial exchanges.The Centre for Excellence could also become a first point of contact for IS in Europe and help in the integration of IS principles in policy making, including resolving of current barriers to IS.

The lack of accountability and recognition on the performance achievements of industrial symbiosis initiatives hampers the drive for sustainability of European businesses. The absence of common standards and/or guidelines on how to measure the retention of secondary raw materials in the production loop and the corresponding avoidance of emissions undermines the motivation of businesses to engage in industrial symbiosis activities. Despite the overall economic conditions that are not favouring industrial symbiosis, sustainability-minded businesses are investing in industrial symbiosis and they can benefit from improved visibility on the impact of their sustainability efforts in industrial symbiosis. Common standards, voluntary schemes, self-regulatory approaches, compliance seals on recording and reporting the gains achieved through industrial symbiotic exchanges can help reveal the externality costs related to secondary industrial outputs that are oriented to landfilling or incineration while it could be instead possible to retain those resources in another production process. Common standards and seals of compliance could also enhance trust and credibility that are vital for businesses in order to conduct a transaction with another business counterpart. As this research has shown, spontaneous and bottom up approaches are far more effective and resilient in delivering results. One key contribution of the centre of excellence could be the development of a framework for assessing IS and even the initiation of standardisation efforts for IS implementation through the creation of an IS standard in association with CEN and other standardisation bodies (e.g. Slovenian Institute of Standardisation – SIST, BSI, ISO).

A centre of excellence could also provide coaching and support to IS regional programmes to maximise impact and contribute to assessing and monitoring of IS impact through systematic gathering of validated data from regional programmes. The centre could also provide support and coaching to policy-makers to understand key obstacles to IS implementation and available policy instruments that could contribute to promote IS.

The Figure 34 below summarises a qualitative assessment of the three options explored.

Figure 34 Options assessment for an EU-level platform for IS

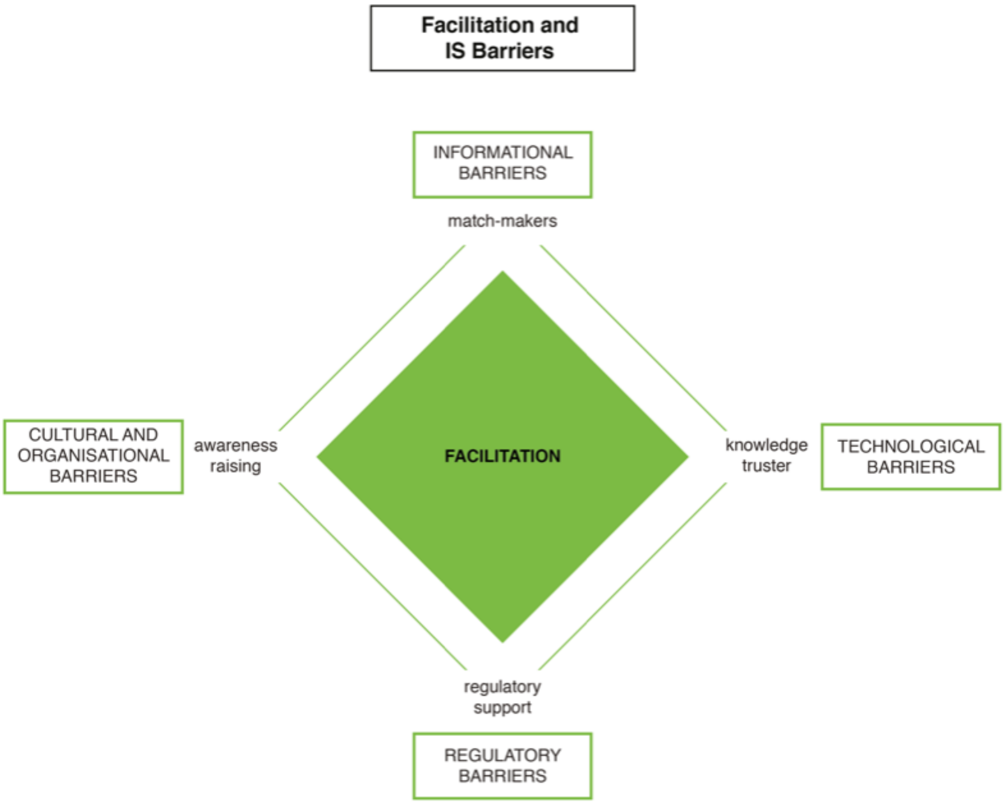


Source: authors, elaborated based on stakeholder discussions

8. Lessons learned and Recommendations

The market analysis shows potential for IS in Europe. IS networks have proven effective in moving waste up the waste hierarchy and achieving diversion from landfill and recovery of valuable materials at a relatively low cost. In addition to successes regarding material wastes, successful industrial symbiosis networks have evidenced multiple additional benfits in terms of reducing carbon, water usage and virgin materials, all of which have led to additional sales, cost reductions, demand pull on innovation and creation and safeguarding of jobs (net of any rebound effects). Examples of successful self-organised activity exists in Europe and also there is anecdotal evidence of non-reported activity in Europe's manufacturing hubs. However, IS implementation also faces a number of barriers which contributes to explain slow uptake of IS solutions. Facilitation may play a role in overcoming some of these barriers as shown in Figure 35.

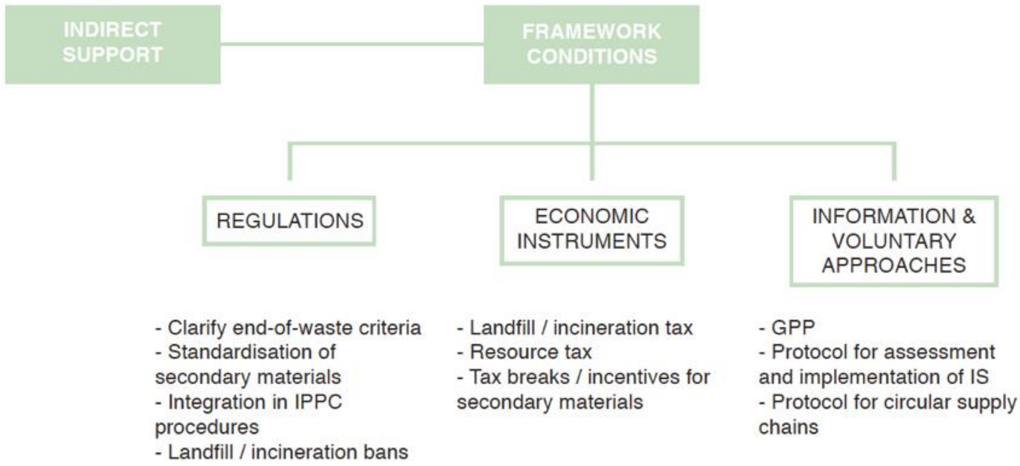
Figure 35 The role of facilitation in tackling IS barriers



Source: authors

Policy intervention is justified on the basis of market and system failures related to IS implementation. Direct and indirect support policies could help to overcome some of the barriers identified in this study. Indirect measures focus mainly on setting adequate framework conditions that help to materialise win-win-win opportunities of IS. Direct support refers to measures whose main aim is to promote IS activity through specific instruments or establish the necessary knowledge base for IS implementation. Direct support could take many forms that vary from development of standards, dissemination of best practices to facilitation of networks, financing mechanisms or the introduction of IS principles in planning and licensing activities. Indirect and direct measures tend to work synergistically. Adequate framework conditions are key foundations to increase effectiveness of direct intervention. The consultation process has emphasised the need to set adequate framework conditions and address current main barriers limiting the potential for waste transformation and reutilisation as a priority action for the EU. There is also evidence (e.g. Manchester Economics report in the case of NISP) that industrial symbiosis supported by public investment provides a competitive return on investment as compared with other public policy initiatives.

Figure 36 The policy framework for indirect support of IS



Source: authors

Key policy recommendations derived from the study are listed below and can be classified into the following key areas:

A. Definition of suitable framework conditions to drive the adoption of IS solutions, including addressing current barriers to IS implementation;

B. Development of a knowledge base and harmonised frameworks for assessment of IS;

D. Planning instruments

C. Fiance and strategic investment in IS

E. Support of actions encouraging spontaneous networking and bottom-up approaches.

A. FRAMEWORK CONDITIONS FOR IS IN EUROPE

The study has concluded that adequate framework conditions are necessary levers to promote IS. Adequate framework conditions cover areas such as well-functioning secondary markets and harmonised criteria for ‘End of Waste’ status. Key framework conditions identified in the study should do the following:

1. Increase cost of landfill and incineration to promote reutilisation of materials (potentially through exploring the possibility of raising landfill taxes).

2. Introduce landfill bans and adequate implementation through standardised acceptance.

3. Clarify the concept of ‘by-product’ and promote harmonised transposition across MS.

4. Consider extending the scope of ‘by-product’ to residuals with a direct application in other sectors of activity with no or very reduced market value.

5. Clarify procedure for ‘End of Waste’ criteria to: 1) harmonise process across different regions and MS; 2) reduce the administrative burden; 3) provide

coaching and detailed guidance for countries/regions with low technical capability; 4) clarify status of 'End of Waste' criteria across borders.

6. Create a register of EoW and data reporting and monitoring guidelines so that information on type and volume of resources transactioned under these concepts ('End of Waste' and by-products) is available for the EU, contributing to clearer identification of areas of potential for IS. This could be done through an online platform at EU level to help users review materials that have obtained the EoW status in other MS.

7. Facilitate transport of waste across borders for IS utilisation through streamlined administrative processes (i.e. similar procedure as 'End of Waste') that ensure safety but also optimal use of resources.

8. Clarify standards for by-products to ensure performance and quality of secondary raw materials and detailed specifications.

9. Introduce incentives for the use of secondary materials.

- This can be done through economic instruments but also through regulatory instruments such as design standards that set minimum requirements for use of secondary materials (introduction of IS principles in the Ecodesign Directive).
- This can be justified as a measure to internalise negative externalities associated with extraction and transformation of primary raw materials, when supported by detailed LCA analysis.

10. Tax border adjustments and introduction of resource taxes may also be necessary to ensure internalisation of externalities for imports to the EU, as some of the noted barriers refer to the difficulty of secondary materials to compete with cheap primary resources.

11. Introduce IS principles for optimisation/reutilisation of materials, water, energy and heat in large developments through planning and building regulations.

12. Add IS principles to GPP policies (particularly relevant for infrastructure projects)

13. Promote supply chain approaches that recognise the value of IS and collective solutions (e.g. treatment and recovery facilities shared by a number of companies, or a circular supply chains voluntary protocol).

B. KNOWLEDGE BASE FOR IS IN EUROPE

14. Enhance the assessment and knowledge base for industrial symbiosis in Europe by:

- Creating a database of IS opportunities, including identification of waste streams with potential, key sectors, technologies and re-purposers. The database should be presented integrated on an online geographical tool.
- Utilising current information (related mainly to IPPC activities) to create a knowledge data-base of waste and material flows using a GIS supported downloadable software.
- Maintaining a monitored database of impact achieved by IS networks in Europe.
- Identifying market potential for specific waste streams as well as levers and barriers for reutilisation (including technological, logistical, infrastructural and economic).

C. PLANNING INSTRUMENTS

15. Promote introduction of IS principles in IPPC procedures and activity licencing to promote better reutilisation of materials, water, energy and heat considering IS opportunities among co-located activities at the regional level.

- Guidelines for introducing IS principles in IPPC procedures
- Offer coaching to national/regional authorities in the implementation process, especially those with low technical capabilities.

16. Introduce IS principles in strategic planning and economic development plans at the local and regional level to:

    a. identify potential for optimisation of material use/reutilisation;

    b. promote heat exchange networks;

    c. identify low carbon sources of energy and

    d. identify opportunities for eco-innovation and inward investment.

- Map resource flows to understand opportunities to recover material, energy, water and heat, using the "accounting" standards from the knowledge base
- Map existing and desirable infrastructure to facilitate synergies. Attention should be paid to examples in the online IS database where old pipelines, trajectories and water management systems were revitalised for IS solutions.

D. FINANCE AND STRATEGIC INVESTMENT

17. Provide (new) financial resources for facilitation of IS to overcome informational and transactional barriers (market failures as well as regulatory or technical barriers). They may also contribute to nurture social networks to facilitate implementation.

18. Develop financial instruments that are more suited for the risk profile of initiatives developing IS or 'circular value chains' projects together with the Circular Economy Finance Support Platform.

19. Support exploration of IS opportunities through R&D by integrating IS principles in priority areas of innovation.

E. OTHER INSTRUMENTS TO PROMOTE SELF-ORGANISED ACTIVITY AND BOTTOM UP APPROACHES

20. Developing harmonised standards and assessment frameworks to measure impact from IS activity. This could not only allow for better comparison across initiatives (and thus enhancing knowledge of IS potential) but would also contribute to best practice sharing and dissemination (e.g. International Synergies, SIST, BSI and CEN has started a process for a CEN Workshop Agreement (CWA) which is an initial phase in progressing towards defining a standard on IS, initially at a European level and possibly leading to a full ISO)

21. Connected to the point above, creating voluntary approaches for reporting IS activity both for industries and regions could create incentives for companies to engage in IS activity which could link to corporate responsibility

22. Self-regulatory approaches and voluntary agreements could also be negotiated between industrial partners to identify opportunities to optimise the use of resources through IS type of approaches while enhancing the image of a region

or area and attracting forward-thinking companies that may have complementary needs

Figure 37 Policy recommendations to scale-up IS initiatives

Framework conditions for IS in Europe	EU	National	Regional	Local
Increase cost of landfill and incineration to promote reutilisation of materials (potentially through exploring the possibility of raising landfill taxes).	√	√	√	√
Introduce landfill bans and adequate implementation through standardised acceptance.	√	√	√	
Encourage transposition and adoption of the (legal process of authorisation) of the concept of "by-product" and reduce complexity of its application across borders	√	√		
Consider the application of the concept of 'by-product' or other legal concept for those resources which have a direct application but have a very small (close to zero) market value	√			
Clarify procedure for 'End of Waste' criteria to: 1) harmonise process across different regions and MS; 2) reduce the admin burden; 3) provide coaching and detailed guidance for countries/regions with low technical capability; 4) clarify status of 'End of Waste' criteria across borders	√	√		
Create a register of EoW and data reporting and monitoring guidelines so that information on type and volume of resources transactioned under these concepts is available for the EU, contributing to clearer identification of areas of potential for IS. This could be done through an online platform at EU level to help users review materials that have obtained the EoW status in other MS.	√			
Facilitate transport of waste across borders for IS utilisation through streamlined admin processes (i.e. similar procedure as 'End of Waste') that ensure safety but also optimal use of resources	√	√		
Clarify standards for by-products to ensure performance and quality of secondary raw materials and detailed specifications	√	√		
Introduce incentives for the use of secondary materials. This can be done through economic instruments but also through regulatory instruments such as design standards that set minimum requirements for use of secondary materials (introduction of IS principles in Ecodesign Directive). This can be justified as a measure to internalise negative externalities associated with extraction and transformation of primary raw materials, when supported by detailed LCA analysis.	√	√		

Framework conditions for IS in Europe	EU	National	Regional	Local
Tax border adjustments and introducing resource taxes may also be necessary to ensure internalisation of externalities for imports to the EU, as some of the noted barriers refer to the difficulty of secondary materials to compete with cheap primary resources.	√	√		
Add IS principles to GPP policies (particularly relevant for infrastructure projects)	√	√	√	√
Promote supply chain approaches that recognise the value of IS and collective solutions (e.g. treatment and recovery facilities shared by a number of companies or a circular supply chains voluntary protocol)		√	√	√

Knowledge base for IS in Europe	EU	National	Regional	Local
Create a database of IS opportunities, including identification of waste streams with potential, key sectors, technologies and re-purposes. The database should be presented integrated in an online geographical tool.	√	√		
Utilise current information (related mainly to IPPC activities) to create a knowledge database of waste and material flows using a GIS supported downloadable software.	√	√		
Maintain a monitored database of impact achieved by IS networks in Europe.	√	√		
Identify market potential for specific waste streams as well as levers and barriers for reutilisation (including technological, logistic, infrastructural and economic).	√			

Planning instruments	EU	National	Regional	Local
Planning instruments A: Promote introduction of IS principles in IPPC procedures and activity licencing to promote better reutilisation of materials, water, energy and heat considering IS opportunities among co-located activities at the regional level				
Guidelines for introducing IS principles in IPPC procedures	√	√	√	√
Offer coaching to national/regional authorities in the implementation process, especially those with low technical capabilities	√			
Planning instruments B: Introduce IS principles in strategic planning and economic development plans at the local and regional level to: a) identify potential for optimisation of material use/ reutilisation; b) promote heat exchange networks; c) identify low carbon sources of energy and d) identify opportunities for eco-innovation and inward investment.				
Map resource flows to understand opportunities to recover material, energy, water and heat, using the "accounting" standards from the knowledge base		√	√	√
Map existing and desirable infrastructure to facilitate synergies. Attention should be paid to examples in the online IS database where		√	√	√

Planning instruments	EU	National	Regional	Local
old pipelines, trajectories and water management systems were revitalised for IS solutions.				
Introduce IS principles for optimisation/reutilisation of materials, water, energy and heat in large developments through planning and building regulations	√	√	√	√
Self-regulatory approaches and voluntary agreements could also be negotiated between industrial partners to identify opportunities to optimise the use of resources through IS type of approaches while enhancing the image of a region or area and attracting forward-thinking companies that may have complementary needs	√	√	√	

Finance and strategic investment	EU	National	Regional	Local
Provide (new) financial resources for facilitation of IS to overcome informational and transactional barriers (market failures as well as regulatory or technical barriers). They may also contribute to nurture social networks to facilitate implementation.	√	√	√	√
Develop financial instruments that are more suited for the risk profile of initiatives developing IS or 'circular value chains' projects together with the Circular Economy Finance Support Platform.	√			
Support exploration of IS opportunities through R&D by integrating IS principles in priority areas of innovation.	√	√		

Other bottom-up approaches to promote IS	EU	National	Regional	Local
Developing harmonised standards and assessment frameworks to measure impact from IS programmes that allows for better comparison across initiatives and best practice methodologies through voluntary protocols (e.g. BSI and CEN has started a process for a CEN Workshop Agreement (CWA) which is an initial phase in progressing towards defining a standard on IS, initially at the European level and possibly leading to a full ISO)	√	√		
Creating voluntary approaches for reporting of IS activity both for industries and regions that contribute to better communication and awareness	√	√		

9. Appendix A – Mapping Of IS Networks' Results

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
DK	Kalundborg	9 industries	regional	N/A	approx. 50	self-organised	N/A	4.614 jobs	Avoided waste (1997): - 1million m3 of water treatment sludge - 200.000 tons of fly ash and clinker - 80.000 tons of scrubber sludge - 2.800 tons of sulfur CO2 emissions reduced by approx. 300.000 tons annually
FI	Kemi-Tornio	7 industries	regional	N/A	5 (riffler waste, ash and ash-mixtures, solid waste, CO2)	mixed model with anchor tenant	estimated at 200 million EUR annually	N/A	N/A
SE	Händelö	difficult to count due to unclear geographic boundaries; basic interaction between 3 industries	local	N/A	6 (CO2, solid waste, grain, organic waste, wastewater, household waste)	self-organised with anchor tenant	N/A	not substantial job creation from IS	N/A
NO	Eyde Network	33 industries	regional	N/A	N/A	facilitated	not yet clear	3.794 jobs	projects are in early stages, not yet quantified

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
Iceland	Svartsengi	11 industries	local	N/A	5 (lukewarm seawater, geothermal brine, electricity and heating water, fish oils, fish offal)	planned with anchor tenant	N/A	630 jobs	N/A
HU	NISP-Hungary	496 industries	national	72 synergies identified during the workshop	N/A	facilitated (EU Life+)	N/A	N/A	3.751 tons of CO2 prevented 1.238 tons of virgin resources saved 26.035 m3 of water saved 1.200 tons of waste diverted from landfill
HU-SK	REPROWIS	N/A	national	N/A	N/A	facilitated (EU Life+)	N/A	N/A	N/A
AT	Styrian recycling network	28 companies part of the recycling network;	regional	N/A	14 (district heating, fly ash, gypsum, wood shaving, waste wood, fibre sludge, waste paper, waste oil, scrap tires, scrap iron, cinder sand, excavated material)	self-organised, driven by individual business interests		22.943 jo bs	approx. 1 million tons of by-products gathered, 780.000 tons are recycled; 200.000 tons are landfilled or incinerated; 25.000 tons are handed to professional waste management (1996). Further 330.000 tons were identified in 1998. 70% recycling rate 42% CO2 emissions saved 25% of final energy

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
									consumption is renewable
AT	GreenTech Cluster	200 companies part of the "Green Tech Valley" of Styria	regional	numerous	numerous	facilitated	15% growth in investment per year 18% growth in employees per year	createin of more than 1.000 jobs/year	
BE	Essenscia Brussels	240 participation organisations	regional	1.500 streams	N/A	facilitated	N/A	N/A	N/A
RO	NISP ECOREG	241 industries	national	638 resource flows, 246 potential synergies	194 synergies completed	facilitated (EU Life+)	N/A	38 jobs	139.000 tons of GHG saved 537.000 tons of waste reused (including 30.000 tons of construction and demolition waste, 500.000 tons of wood waste, 2.891 tons of animal and food waste, 245 tons of plastic waste, and 20 tons of Waste Electrical and Electronic Equipment - WEEE) 3.000 ha of forest preserved

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
SK	Bratislavsky Kraj / ERDF	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A
BE	werecycle.be	19 industries	national	N/A	23 resources are actively circulated within the network	web based facilitated	N/A	N/A	111.357 tons of plastic recycled (2015) 70.403 tons of tyres recycled (2015)
PL	EUR-IS Wroklaw	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A
FR	PNSI	N/A	national	more than 600 process identified through workshops	N/A	planned	N/A	N/A	N/A
NL	Silver Project	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A
NL	Rotterdam Harbour	69 potential industries	local	N/A	N/A	facilitated	N/A	N/A	N/A
FI	FISS	586 industries	national	4.418 resources	N/A	facilitated	N/A	N/A	N/A
IT	ENEA Italian Network	568 industries in Sicily 258 in Catania and Siracusa districts (major districts of network)	regional	21 resources shared Catania: 88 input, 187 output Siracusa: 91 input, 187 output	Catania: 165 matches Siracusa: 529 matches	facilitated	N/A	N/A	N/A
IT	Industrial Park of Rieti-Cittaducale	240 industries	local	N/A	N/A	facilitated in an established industrial estate	N/A	4.300 jobs (estimation)	N/A

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
DK	Green Industrial Symbiosis Denmark	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EU	EUR-ISA	N/A	national	N/A	N/A	facilitated with specialists from the private sector	N/A	N/A	N/A
FI	Harjavalta	13 industries	local	N/A	6 (copper sulphate, iron sand, copper telluride, selenium, nickel matte, PGM concentrates) 8 waste management processes	self-organised	N/A	1.000 jobs (estimation)	Long term waste management. 81,8% utilisation level of waste: - 351 t/y from energy waste - 181 t/y from metal waste -83 t/y from led waste - 124 t/y from hazardous waste - 15 t/y from paper waste -16 t/y from household waste
UK	Wildling Butler	1 industry	local	N/A	N/A	self-organised	N/A	N/A	N/A
EU	ZeroWin	10 case studies	N/A	N/A	N/A	N/A	N/A	N/A	341 TWh of energy saved (estimation by 2020)
IE	SMILE	N/A	national	N/A	N/A	facilitated / web-based	N/A	N/A	N/A
DE	Knapsack	27 industries	local	N/A	N/A	self-organised	N/A	2.200 jobs	N/A

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
FR	Bazancourt-Pomacle	58 total (20 industrial corporations, 38 SMEs)	local	N/A	8 major symbiotic processes (water, steam, effluents, products, R&D, energy, organisation, drilling)	self-organised	N/A	1.200 - 2.000 jobs	N/A
BE	Symbioseplatform	300 organisations	regional	N/A	2.000 streams and technologies	planned / web-based	N/A	N/A	goal of achieving 15% less waste
NL	Biopark Terneuzen	22 industries (7 of which part of a symbiosis network)	local	N/A	14 (biomass, wastewater, clean water, heat, CO_2, electricity, steam, starch residues, energy)	planned	N/A	N/A	N/A
PT	Organised Waste Market	N/A	national	N/A	N/A	planned / web-based	N/A	N/A	N/A
ES	ResidiRecurso	4.700 companies involved	regional	N/A	~ 260 announcements (75% supply and 25% demand) as of May 2013	facilitated / web-based	N/A	N/A	N/A

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
GR	symbiosis.gr	164 industries	national	N/A 38,5% synergies at the stage of idea	23,1% of synergies completed 23,1% of synergies in negotiations 7,7% of synergies in discussion 7,6% of synergies implemented	facilitated (EU Life+) / web-based	N/A	N/A	N/A
ES	Manresa	N/A	regional	N/A	N/A	facilitated	N/A	N/A	N/A
UK	NISP NI	1.900+ members	regional	N/A	448 completed synergies	facilitated	£25 million business cost savings £16.2 million additional sales £1.9 million private investment	35 jobs created 61 jobs secured	(2007-2017) - 392.000 tonnes of waste diverted - 12.700 tonnes of hazardous waste saved - 240.000 tonnes of virgin raw materials saved - 340.000 tonnes of CO_2 saved
UK	NISP Scotland	N/A	regional	N/A	127 synergies completed (around 35 per year)	facilitated	£4.19 million cost savings to industry £7.22 million private investment 1.8 million additional sales	38 jobs created	312.295 tonnes of waste diverted from landfill 194.183 tonnes of CO_2 saving

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
SI	Slovenia E-Symbioza	around 20 companies have listed materials / waste demands	regional	N/A	N/A	facilitated / exclusively web based	N/A	N/A	N/A
UK	LISP - London	3 on-site facilities 5+3 more under planning permission)	local	N/A	on-going development	planned eco-industrial park	N/A	60-100 jobs	35.000 tonnes/year of plastic bottle recycling 35.000 tonned/year of food and green waste into 31.000 MWH per annum and achieves savings of 16.325 CO2 per year (only from AD)
IT	Rethink Italy	25 members	regional	N/A	5 synergies	facilitated / web-based	N/A	N/A	N/A
FR	Orée	15 members	N/A	N/A	4 synergies	facilitated	N/A	N/A	N/A
FR	Inex	100 members	N/A	N/A	15 synergies	facilitated	N/A	N/A	N/A
	Monsteras	N/A	N/A	N/A	10-20 active synergies	facilitated	N/A	N/A	N/A
SE	Industrial Park of Sweden	17 industries	local	N/A	N/A	planned industrial park	difficult to calculate	3.794 jobs	7.500 tonnes/year of Carbon Dioxide Emissions reduced 1,6 million tonnes of CO2 emissions reduced Reductions in GHG, Nitrogen and Phosphorus enabled by: - reduction of fossil fuels used - reduced need for

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
									artificial fertiliser - increased use of locally produced biogas - reduced amount of waste placed in landfills - increased environmental awareness
SE	Oresundskraft	6 production plants	regional	N/A	7 active synergies	self-organsied	N/A	N/A	N/A
SE	Nordvästra Skånes Renhållning	N/A	regional	N/A	7 active synergies	self-organised	N/A	N/A	N/A
SE	Nordvastra Skanes Vaten och Avlopp	N/A	regional	N/A	4 active synergies	self-organised	N/A	N/A	N/A
SE	Linkoping IS Network	11 industries with symbiotic processes	regional	N/A	22 symbiotic processes	self-organised	N/A	N/A	CO2 emissions linked to heating reduced from 64 296 t/y in 1985 to to 4 700 t/y in 2006 – a reduction of 93%. Reductions of around 18 000 tonnes/year of CO2 equivalent are enabled by the production of biogas and its use as a transport fuel Between 1985 and 2006, SOx emissions were reduced from 355

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
									t/y to 55 t/y, and NOx emissions were reduced from 146 t/y to 8 t/y. 30 000 m3 of oil is avoided by the district heating system. With the use of biogas, 6 500 m3 less diesel is needed in the region. 90 000 tonnes/year of landfill reduced
SE	Enkoping IS Network	N/A	regional	N/A	5 major synergies within the network. 10 synergies outside the network	self-organised	CHP is believed to have reduced its cost for fuels by 2,5 MSEK/year Several economic benefits from the use of alternative resources but not quantified	N/A	Recovery of Phosphorus and Nitrogen: By using sewage water as fertilizer more than 1 ton of phosphorus is recovered back into the cultivated system. Through the use of effluents in willow plantations, the WWTP has reduced the nitrogen discharges by 30 t/year– corresponding to a 25% reduction. Removal of Cadmium from soil Reduction in GHG

Country	Network	Network size	Network scope (local/ regional/ national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated/ planned/ self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified
SE	Stenungsund IS Network	7 industries	regional	N/A	7 synergies	self-organised	N/A	N/A	15.000 tonnes/year of GHG emissions reduced Chemical industries use of 424.000 tonnes of natural gas instead of fuel gas
SE	Avesta IS Network	8 industries	regional	N/A	13 synergies	self-organised	N/A	N/A	N/A
DE	Heidelberg industrial estate of Pfaffengrund	18 enterprises participating in symbiotic processes	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DE	Rhein Neckar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

10. Appendix B Detailed overview of market potential estimates per sector

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
Plastics[68]	General -- In Europe over 40% of plastics are used in packaging, 20% is used in construction and less than 10% by the automotive industry.[69] Other common applications include	From Eurostat: Plastic waste (W074) generation of 17 m tonnes in 2014, of which 75% was treated. Of treated waste: 80% recovered 6% landfill/disposal 1% incineration/disposal	- Re-use as feedstock in new plastics - Construction sector - Agriculture - EEE - Cars, vehicles productionClothing, bags, furniture	• Plastics/packaging sector • Construction industry • Agriculture • Electronics industry • Automotive industry • Textile industry	If the approximately 6.8 m tonnes (40%) of untreated, landfilled and incinerated plastic waste was to be recovered then this could, at a price of around €250-350 per tonne[72], be worth up to €2.4 billion per year[73]

[68] The classification of plastics in the next column has been taken from JRC (2014) End-of-waste criteria for waste plastic for conversion
[69] EC (2017) Strategy on Plastics in a Circular Economy - Roadmap
[72] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Price_indicator_and_trade_volume_for_plastic_waste_in_EU-28_till_December2013_update3.PNG
[73] Own calculation based on market prices and volumes as described.

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
	furniture, household appliances, electric and electronic goods and agricultural uses. Specific types: PET (Polyethylene Terephthalate), HDPE (High-density Polyethylene), PVC (Polyvinyl Chloride), LDPE (Low density Polyethylene), PP (Polypropylene), PS (Polystyrene), Other – BPA, Polycarbonate, LEXAN.	14% incineration/energy recovery. Therefore approximate available volumes of 6.8 m tonnes exist (untreated + all non-recovered volumes). Other sources: In 2014, 25.8 million tonnes of post-consumer plastics waste ended up in the official waste streams. 69.2% was recovered through recycling and energy recovery processes while 30.8% still went to landfill.[70] Within the different plastic applications, plastic packaging is the most widely recycled one with a recycling rate of 39.5% in 2016.[71]	- Fuel and gasification. The plastics could be used as a fuel energy source via incineration or converted into different chemical streams via gasification Specifically: PET: Recyclable into e.g. new PET bottles (for food and drink applications) as well as other lower-value products and textiles. HDPE: Used to make picnic tables, plastic lumber, waste bins, park benches, bed liners for trucks and other products which require durability and weather-resistance. Plus reuse within the plastics sector. PVC: Hardly recyclable, contains many toxic materials Products of PVC may be repurposed but not reused for anything involving food, children, etc. LDPE: Reusable, not always recyclable e.g.		and would represent a doubling of the existing market. New, innovative delivery models and evolving use patterns make reuse economically attractive for at least 20% of plastic packaging -- personal and homecare bottles and carrier bags alone could generate about 6 million tonnes of material savings globally (by weight), worth at least USD 9 billion (€7.8 billion).[74]

[70] Plastics Europe (2016) Plastics – the facts 2016
[71] Plastics Europe (2016) Plastics – the facts 2016
[74] World Economic Forum and the Ellen MacArthur Foundation (2017). The New Plastics Economy: Catalysing action report

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
			Plastic lumber, landscaping boards, garbage can liners and floor tiles. PP: Reusable and recyclable e.g. Landscaping border stripping, battery cases, brooms, bins and trays. Plus reuse in new applications. PS: Sometimes reusable, partly recyclable e.g. Packaging chips can be reused. Plus energy and gasification. Other: Normally non-reusable, non-recyclable. Polycarbonates are reused in blast media applications (replacement for sand blast media).		
Food waste	General (e.g. vegetable and animal food waste i.e. Dairy, meat, legumes and seeds,cereals, breads, rice, vegetables and fruits. Specific sources: Primary Production (from farming), Processing (from food manufacture), Distribution (supermarkets), Consumer (households).	From Eurostat: Animal and mixed food waste (W091) and vegetal waste (W092) generation of 77.4 m tonnes in 2014, of which 80% was treated. Of treated waste: 90% recovered 3% landfill/disposal 1% incineration/disposal 5% incineration/energy recovery. Therefore approximate available volumes of 21.2 m tonnes exist	Food waste destinations are rather homogenous independently of the type: - Animal feed - Composting - Bio-energy - Bioplastics - Pharmaceutical products - Nutraceuticals applications	• Agriculture • Energy sector • Chemical sector • Pharmaceutical industry	It has been estimated in two EC Impact Evaluation studies that €100-425 million per year (2013-2020) net benefits (80% in the form of environmental improvements) would result from the introduction of compulsory separated collection and biological treatment[78]. A policy such as the Food Waste Reduction

[78] PPi4waste project deliverable - D2.4 State of the Art of Emerging Solutions- based on 2 scenarios of bio-waste collection and removal from treatment facilities, from 36.5%-100%.

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
	For food waste the level of refined data decreases throughout the supply chain. By weight food waste is generated primarily at the consumer and distribution levels of the chain, followed by processing and in the last place production).[75]	(untreated + all non-recovered volumes). Other sources: Around 88-100 million tonnes of food are wasted annually in the EU, with associated costs estimated at 143 billion euros.[76] Each year in the EU 118-138 Mt bio-waste is generated[77]. Of which around 88 Mt originate from municipal waste (30-40% of all municipal waste).			Policy in South Korea which uses food waste for fodder and compost) adopted by the EU to Internally produce animal feed and fodder (instead of importing such) would generate savings in the order of €10.4 billion annually for livestock holders in the agri-sector in Europe[79].
Critical Raw Materials	Waste Electrical and Electronic Equipment (WEEE)	In 2012, WEEE produced in Europe 9.5 Mt[80], WEEE 3.3 Mt (35%) collected for treatment.[81]	. Recovery of metals, rare earths and other valuable materials, for example Lithium, Copper, Carbon Monoxide and graphite from Lithium-Ion batteries; . Most valuable sources include CRT, LCD and LED monitors, smart	• Electronics Manufacturing	A study focusing specifically on this potential found a market of up to €2.1 billion based on current levels of WEEE, increasing to €3.7 billion in future[82].

[75] FUSIONS (2014) Report on review of (food) waste reporting methodology and practice
[76] FUSIONS (2016). Estimates of European food waste levels
[77] http://www.ppi4waste.eu/
[79] COWI (2011).
[80] http://closeweee.eu/
[81] http://closeweee.eu/
[82] Cucciella, F., et al (2015)

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
			phones, TVs and tablets. . Recovery of glass and plastics		
	Aluminium Around 12.5Mt of aluminium is consumed in the EU each year[83].	The EU produces around 4.7 Mt of aluminium each year from recycled scrap, but at the same time also exports around 0.5-0.7Mt of aluminium scrap each year. The high value of the material and long-standing recycling activities means that current recycling rates are high, at >90% in construction and automotive, >60% from food packaging. Actual available volumes for recovery are unclear but expected to be relatively low.	Metals can generally be recycled to a high level. For example: Aluminium cans can be recycled over and over again in a "closed loop" without loss of quality and saving energy (around 95%) and environmental impacts compared to the production and use of primary aluminium.	• Beverage industry • Food packaging • Metal production	Scrap aluminium is worth around €500-€1 500/tonne, therefore every extra 0.1 Mt of recycling would potentially represent a market of around €50-€150 m per year. Potential remains to increase recycling rates, particularly for food packaging. Previous studies found that if the EU would introduce a deposit-based recycling system for aluminium beverage cans similar to the Swedish system, the estimated economic benefits for operators of aluminium recycling systems in EU-27 would be €20 m per year[84]. The potential of a recycling system similar to the Belgian system would be €7.4-€28 m[85].
	Solar panels	With an assumed lifetime of 25 years for most solar PV panels then current volumes for	Recycling into new panels, retrieval of valuable materials. In the case of solar	• Glass foam industry • Glass insulation industry • Industrial production	The current solar module market is worth around €3-4 billion euros per year in the EU, although

[83] Figures all from http://www.european-aluminium.eu/
[84] COWI (2011).
[85] COWI (2011).

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
		recycling and recovery will be equivalent to solar installations in 1992, i.e. very low. Yet these volumes will be increasing every year, with 2004 the first year that 1 GW of solar PV was installed in the EU and this increasing to more than 20 GW in some subsequent years such as 2010. This will therefore be an important future waste stream.	photovoltaics (PV), suitable collection systems could aspire to collect up to 90% of the PV waste throughout Europe (collection rate in 2013 was 40%), and to retrieve up to 90% of the high value components and raw materials such as semi-conductors, silicon, glass, aluminium, copper, silver, Indium, selenide and gallium.		a high share of panels are now made outside the EU, therefore limiting direct demand for the recovered materials in EU manufacturing. Raw materials that can be recovered include silver, copper and rare earths, each of which are highly valuable and with applications in the solar and other industries. High value materials can also be competitive to trade internationally, i.e. to solar producers in other countries. Despite the high value of the embedded materials there are concerns that recycling remains unprofitable at current resource prices, therefore current market potential is estimated to be low, at only €0.5 million per year[86]. If recycling techniques can be significantly improved and/or resource prices increase then this market potential can also increase. This will be important given the significant increase in EoL PV panel volumes in the next 10-20 years.

[86] Cucciella, F., et al (2015)

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
Construction and Demolition Waste (C&DW)	General Specific types: Concrete, Bricks, tiles, ceramics, Roofing, Insulation, Wood, Carpets, Plastic pipes, Organics(e.g. prunings, trimmings, branches), Metals, Gypsum, Glass, Hazardous waste, Miscellaneous.	Eurostat: Mineral waste from Construction and Demolition (W121) generation of 297 m tonnes in 2014, of which 94% was treated. Of treated waste: 88% recovered 12% landfill/disposal 0% incineration/disposal 1% incineration/energy recovery. Therefore approximate available volumes of 51.3 m tonnes exist (untreated + all non-recovered volumes). Other sources: EU-28 currently generates 461 Mt per year of C&D waste. Expected to reach around 570 Mt between 2025 and 2030[87]. Of the 450-500 million tonnes of C&D waste generated every year in Europe, at least a third is concrete.[88] The composition of C&D waste varies per MS: Concrete (12-40% of the	Non-hazardous waste sent to landfill offers the largest potential source for recovery. Most materials can be re-used or recycled, with mineral materials most often able to be re-used directly or used as input into production of new products. These are by volume by far the largest waste streams. Although 196 Mt of waste (42%) is currently recycled into aggregates, representing around 8% of EU annual production of 2,500 Mt[90].	• Construction • Manufacture of clay building materials • Agriculture • Infrastructure - roads	The total volumes and treatment of waste volumes are unclear with Eurostat and industry sources differing significantly. Current estimates from the aggregates market show a market of around €0.8 billion/year for currently recovered C&DW. If maximum recycling potential could be increased to 75% of produced C&D waste (from around 40%), the market would increase to €1.4 billion per year, and more in future as projected waste streams grow[91]. A potential growth of €0.6 billion. A previous study[92] estimated cost savings of €3.8 billion and tax revenues of €5.7 billion across the EU28 if an aggregates levy similar to that applied in the UK was applied.

87 Http://hiserproject.eu/
88 CEMBUREAU (2016) Cement, concrete & the circular economy
90 http://www.uepg.eu/statistics/estimates-of-production-data/data-2015
91 Potential based on an assumed average value of €4/tonne for recycled aggregates. Calculated based on 2660 Mt production (EU28+EFTA) and €15 billion turnover per year for the industry. Value per tonne discounted by 25% and rounded to account for sometimes lower quality/desirability of recycled materials. Derived based on http://www.uepg.eu/statistics/current-trends
92 COWI (2011)

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
		waste); Masonry (2-58%); Asphalt (4-26%); Gypsum (0.2-0.4%); Other mineral waste (2-9%); Other-non mineral waste (4.3-46% of the waste)[89]			
Biomass & Bio-based Products	Clothing / textiles. The main groups of textiles can be categorised as follows: household textiles (including leisure textiles such as tents); carpets and rugs; apparel; footwear and handbags; and mattresses.	Eurostat: Textile wastes (W076) generation of 2.3 m tonnes in 2014, of which 81% was treated. Of treated waste: 83% recovered 8% landfill/disposal 1% incineration/disposal 8% incineration/energy recovery. Therefore approximate available volumes of 0.76 m tonnes exist (untreated + all non-recovered volumes). Other sources: At EU level, 1.3 million tonnes unused clothing and textile resources annually have recycling potential[93]. Other sources point at 80,000 tonnes residual textile waste generated in EU each year[94].	Reuse as textiles i.e. carpets, automotive industry, agro-textiles, automotive leather and various other materials. Ot processing into chemicals feedstocks.	• Plastics sector • Construction • Textile industry • Automotive industry • Agriculture • Energy recovery • Rubber industry • Energy industry • Civil engineering	Based on an average price for used textiles of €250-350/tonne[95] an estimated market potential of up to €270 m can be estimated. This chimes with a UK report identifying a promising opportunity (by weight) fo reducing waste from textiles discharges by households, mainly clothing.[96] Recovering just 10% of this residual waste would generate a potential sales value of almost £25 million (equivalent to €). From the EU Resyntex project - organising a value chain in which textile waste gets collected and transformed into new

[89] BIO Intelligence Service, Arcadis & IEEP. (2011) Management of Construction and Demolition Waste. Brussels: European Commission
[93] COWI (2011).
[94] http://www.resyntex.eu/
[95] http://www.letsrecycle.com/prices/textiles/
[96] WRAP (2011) Textiles flow and market development opportunities in the UK

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
					feedstock for chemicals and textiles up to 50,000 tonnes could be reused[97]. The volume and value of the chemical and textile feedstocks is unclear, but could be high, for example PET bottle recyclate, is worth around €1,000 per tonne, therefore 10,000 tonnes equivalent would represent a market value of €10 million. Reuse of the estimated 1.3 Mt of textiles is estimated to be equivalent to annual savings of €56 million on landfill taxes in the EU.[98]
	Natural rubber Primarily from used tyres.	Eurostat: Rubber waste (W073) generation of 3.3 m tonnes in 2014, of which 80% was treated. Of treated waste: 45% recovered 1% landfill/disposal 1% incineration/disposal 45% incineration/energy recovery. Therefore approximate available volumes of 1.9	. Tyres, tubes . Hygiene products . Energy fuel . New tyres . Crumb rubber products (e.g. synthetic turf) . Energy recovery, burned for fuel . Civil engineering applications e.g. breakwaters, erosion		Currently, natural rubber is traded at around €1700/tonne on the global market, but crumb rubber (one of the main recovered products from treated rubber) has a value of closer to €60/tonne[101], suggesting a maximum market potential of around €115 m.

[97] http://www.resyntex.eu/
[98] COWI (2011). Economic analysis of resource efficiency policies. A study commissioned by DG Environment
[101] https://www.smithersrapra.com/SmithersRapra/media/Sample-Chapters/Recycling-and-Re-use-of-Waste-Rubber.pdf

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
		m tonnes exist (untreated + all non-recovered volumes). Other sources: More than 3.3 million tons of used tires every year in Europe.[99] The recovery rate of tyres is currently 95% - of which 38% material is recycled; 38% energy recovered; 10% retreaded & reused[100]. Around 2.5 mt end of life tyres and 3.2 mt used tyres available as raw materials each year.	control, highway crash barriers		For tyres: assuming 30% by weight of the rubber is replaced with Rubber Regenerating and Processing (RRP), this will make a saving of €350/tonne in addition to savings with regard to transport/shipment, material handling and storage.[102] Previous reports have found limited market potential with current recycling techniques which are marginal or non-competitive in current markets[103]. Although the situation appears to be improving.[104]
	Wood	Eurostat: Wood waste (W075) generation of 50.3 m tonnes in 2014, of which 87% was treated. Of treated waste: 46% recovered 1% landfill/disposal 1% incineration/disposal	• Derived timber products, paper pulp for packaging or hygiene paper. • Animal bedding • Energy recovery • Building material • Floor covering • Pin boards		Prices per tonne of waste wood are relatively low and in some markets negative. Prices ranging from around -€60 up to €90/tonne[105,106]. With negative prices representing recyclers charging municipalities or firms to dispose of the

[99] http://www.ecorub.se/
[100] DTI, Ecorys, REC, 2013. Treating Waste as a Resource for the EU Industry. Analysis of Various Waste Streams and the Competitiveness of their Client Industries
[102] CORDIS (2016) RETYRE Report Summary
[103] DTI, Ecorys, REC, 2013. Treating Waste as a Resource for the EU Industry. Analysis of Various Waste Streams and the Competitiveness of their Client Industries
[104] https://www.smithersrapra.com/SmithersRapra/media/Sample-Chapters/Recycling-and-Re-use-of-Waste-Rubber.pdf
[105] http://www.wrap.org.uk/content/new-gate-fees-revealed-wrap-show-changes-market and http://www.letsrecycle.com/prices/wood/
[106] http://bioboost.eu/uploads/files/bioboost_d1.1-syncom_feedstock_cost-vers_1.0-final.pdf

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
		52% incineration/energy recovery. Therefore approximate available volumes of 30.1 m tonnes exist (untreated + all non-recovered volumes).			waste wood. This suggests a relatively low market potential for this material per tonne, however with high volumes available and if prices were at the high end of the range this could still be a significant market worth up to €2 700 million per year, although very likely much less.
	Used oils Including: Vegetable oils	Eurostat: Used oils (W013) generation of 4.2 m tonnes in 2014, of which only 56% was treated. Of treated waste: 86% recovered 1% landfill/disposal 4% incineration/disposal 10% incineration/energy recovery. Therefore approximate available volumes of 2.2 m tonnes exist (untreated + all non-recovered volumes).	. Fuels . Lubricants . Coating, painting inks . Asphalt . Additives for plastics . Energy, biofuels . Chemical applications	• Energy recovery • Chemical industry	Used cooking oil has a current market value of around €730/tonne[107], therefore the estimated available volumes of used oils could fuel a market worth up to €1.6 billion.
Other	Metals	Iron and Steel: In 2012, the European steel industry generated about 21.4 Mt slag[108]	. Household appliances . Car production . Highways, bridges, buildings	• Cement industry • Glass industry • Foundry industry • Petrochemical industry Multiple others	About 24% of the 21.4 Mt slag is not being reused[109]. Not re-used

107 https://www.greenea.com/en/market-analysis/ - UCO DDP NEW (Apr 2017)
108 http://www.reslag.eu/
109 http://www.reslag.eu/

CE package priority sector	Waste stream	Volume waste stream (Mt)	Waste applications	Waste destination sector / industry	Market potential and other economic benefits (e.g. cost saving from reutilisation) (€)
			. Military uses (e.g. aircraft carriers and nuclear submarines)		slag estimated value of €140 million /year[110].
	Batteries – automotive batteries, industrial batteries and portable batteries[111]	Eurostat: Batteries and accumulator waste (W0841) generation of 1.7 m tonnes in 2014, of which 88% was treated. Of treated waste: 97% recovered 3% landfill/disposal 0% incineration/disposal 0% incineration/energy recovery. Therefore approximate available volumes of 0.25 m tonnes exist (untreated + all non-recovered volumes). Other sources: Every year, approximately 0.8 m tonnes of automotive batteries, 0.19 m tonnes of industrial batteries, and 0.16 m tonnes of consumer batteries enter the European Union.[112]	Components recovered for other products and production processes. Valuable metals can be recovered including Lithium, Cobalt, Lead, Nickel and Cadmium. Recycled lithium often used as lubricant or in other products, not for new batteries.	. Steel industry . Construction industry . Battery producers	Market values for recovered batteries are unclear. One source indicates that recycling of batteries is not cost effective, aside from lead-acid batteries typically used for cars, but that the increasing scarcity of lithium may make recycling of lithium batteries more attractive over time[113]. In the UK the cost of portable battery collection and processing is estimated at €1 600/tonne (GBP 1 400/tonne).[114]

[110] Price for slag varies by type, granulated or air cooled, the former being more valuable (€50/t) as an additive to cement, the latter (€5/t)only suited as an addition to aggregates. Assuming a 50% split between the two types in EU industry the currently not used volume of slag can be valued.
[111] Distinguished in the Batteries Directive 2006/66/EC
[112] EC(2016) Batteries & Accumulators
[113] http://batteryuniversity.com/learn/article/battery_recycling_as_a_business
[114] http://www.letsrecycle.com/news/latest-news/battery-collection-costs-expected-to-shoot-up/

11. APPENDIX C DETAILED CALCULATIONS OF WASTE STREAMS

Calculation of waste destinations by waste type

We first need to find out which percentage of waste streams is recycled in each member state. In order to do so, we first need to look at the different waste treatment categories. The categories are as follows:

Waste operations categories:

1. TRT Total waste treatment
2. DSP_L Landfill / disposal (D1-D7, D12)
3. DSP_D Deposit onto or into land
4. DSP_O Land treatment and release into water bodies
5. INC Incineration / disposal (D10)
6. RCV_E Incineration / energy recovery (R1)
7. RCV_NE Recovery other than energy recovery
8. RCV_B Recovery other than energy recovery - backfilling
9. RCV_O Recovery other than energy recovery - except backfilling

Of these, we need to exclude TRT as well as RCV_B and RCV_O, as these obviously overlap with the other categories and we only want to include mutually exclusive categories for a calculation of the recycling percentages. In addition, we also exlude the category "Deposit onto or into land" (DSP_D). While this category could plausibly be non-overlapping with "Landfill / disposal", the following table tells us that "Deposit onto or into land" has the waste operation code D1, and thus is a subset of DSP_L, which includes D1-D7 and D12. Furthermore, categories D6 and 7 -- counterintuitively so -- deal with releases into waster bodies. Thus, we also exclude category "DSP_O", as it does not seem to be mutually exclusive with DSP_L.

[! Waste codes table](/Users/ninodavidjordan/Documents/IndustrialSymbiosis/Illustrations/Waste Codes Table.png "Waste codes table"]

After excluding these categories, we group the data by country and waste stream and calculate the proportions attributable to each waste stream. However,

We may have to use the special prop.table function as values / sum(values produces NA values when the original value was 0.

In order to test our results, we sum up all proportions for the total waste of the UK.

Sum_of_proportions

The result is 1, which indicates that we correctly assigned the proportions. To make sure, let's look at a specific waste stream for the UK in separation:

Sometimes we get NA values in our calculations of proportions and percentages of waste streams. This happens when the sum of all values for the different waste operations is 0. As an example, let's look at Albania and waste stream "W011". We can see that here it is entirely justified to obtain NA values.

unit	hazard	wst_oper	Waste	geo	time	values	Proportion_of_waste_stream	Percentage_of_waste_stream	Prop_table
T	HAZ_NHAZ	DSP_L	W011	AL	2014-01-01	0	NaN	NaN	NaN
T	HAZ_NHAZ	INC	W011	AL	2014-01-01	0	NaN	NaN	NaN

T	HAZ_NHAZ	RCV_E	W011	AL	2014-01-01	0	NaN	NaN	NaN
T	HAZ_NHAZ	RCV_NE	W011	AL	2014-01-01	0	NaN	NaN	NaN

wst_oper	waste	Percentage_of_waste_stream
INC	W013	0.000000
RCV_E	W013	0.000000
DSP_L	W013	4.733575
RCV_NE	W013	95.266425

We can see that in the UK waste stream W013 got about 95% recycled and about 5% landfilled.

Now we would like to obtain variance and standard deviation for the recyling percentages of the different waste streams across all countries in the dataset. To do so, we exlude all missing values from our percentage column, only look at recycled values, group by waste stream and then obtain measures of variance and standard deviation. In order to see whether our results are plausible, we now only look at waste stream W013.

unit	hazard	wst_oper	waste	Geo	time	values	Proportion_of_waste_stream	Percentage_of_waste_stream	Prop_table	Variance	Standard_Deviation	Mean_percentages
T	HAZ_NHAZ	RCV_NE	W013	AT	2014-01-01	2299	0.1259174	12.5917406	0.1259174	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	BE	2014-01-01	84298	0.9435745	94.3574475	0.9435745	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	BG	2014-01-01	11445	1.0000000	100.0000000	1.0000000	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	CY	2014-01-01	7778	0.9997429	99.9742931	0.9997429	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	CZ	2014-01-01	2248	0.5335865	53.3586518	0.5335865	1225.785	35.01121	65.67281

T	HAZ_NHAZ	RCV_NE	W013	DK	2014-01-01	54366	0.8374049	83.7404886	0.837404 9	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	EE	2014-01-01	652	0.7563805	75.6380510	0.756380 5	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	EL	2014-01-01	24015	0.9746347	97.4634740	0.974634 7	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	ES	2014-01-01	171329	0.9928375	99.2837482	0.992837 5	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	EU28	2014-01-01	2030000	0.8565401	85.6540084	0.856540 1	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	FI	2014-01-01	19611	0.6434266	64.3426622	0.643426 6	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	FR	2014-01-01	191055	0.6472206	64.7220632	0.647220 6	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	HR	2014-01-01	56	0.0090366	0.9036631	0.009036 6	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	HU	2014-01-01	14419	0.6060186	60.6018577	0.606018 6	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	IE	2014-01-01	135	0.0104175	1.0417470	0.010417 5	1225.785	35.01121	65.67281

T	HAZ_NHAZ	RCV_NE	W013	IT	2014-01-01	217029	0.9547962	95.4796220	0.9547962	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	LT	2014-01-01	1190	0.8940646	89.4064613	0.8940646	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	LU	2014-01-01	915	1.0000000	100.0000000	1.0000000	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	LV	2014-01-01	4202	0.9735867	97.3586654	0.9735867	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	ME	2014-01-01	11	0.4583333	45.8333333	0.4583333	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	MK	2014-01-01	0	0.0000000	0.0000000	0.0000000	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	NL	2014-01-01	40128	0.5212241	52.1224087	0.5212241	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	NO	2014-01-01	15235	0.1327738	13.2773827	0.1327738	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	PL	2014-01-01	139106	0.9907200	99.0719968	0.9907200	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	PT	2014-01-01	24339	0.9993020	99.9302020	0.9993020	1225.785	35.01121	65.67281

T	HAZ_NHAZ	RCV_NE	W013	RO	2014-01-01	8141	0.1776386	17.7638613	0.1776386	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	RS	2014-01-01	4491	0.6843950	68.4395002	0.6843950	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	SE	2014-01-01	7621	0.1849533	18.4953282	0.1849533	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	SI	2014-01-01	799	0.8288382	82.8838174	0.8288382	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	SK	2014-01-01	5942	0.6685419	66.8541854	0.6685419	1225.785	35.01121	65.67281
T	HAZ_NHAZ	RCV_NE	W013	UK	2014-01-01	7366	0.9526643	95.2664252	0.9526643	1225.785	35.01121	65.67281

We draw on the data, which combines waste streams, the treatment they undergo and the landfill costs for different countries.

In a first step we exclude the following waste stream codes, as they represent totals or subtotals:

- TOTAL,
- TOT_X_MIN,
- W12-13 ("Mineral and solidified wastes (subtotal)"),
- W01-05 ("Chemical and medical wastes (subtotal)"),
- W09 ("Animal and vegetal wastes (subtotal, W091+W092+W093)"), W10 ("Mixed ordinary wastes (subtotal, W101+W102+W103)"),
- W06_07A ("Recyclable wastes (subtotal, W06+W07 except W077)"),
- W077_08 ("Equipment (subtotal, W077+W08A+W081+W0841)")",
- W10 ("Mixed ordinary wastes (subtotal, W101+W102+W103)"), and
- W077_08 W077_08 ("Equipment (subtotal, W077+W08A+W081+W0841)")"

We also exclude the following waste stream codes:

- RCV_B,
- RCV_O,
- DSP_D, and
- DSP_O,

as these are subcodes already comprised in overarching landfill and recycling codes.

Now we calculate the *proportions* of waste streams in each country that undergo a specific treatment.

We test the results of this operation by looking at the waste stream "W012" for the UK. We can see that the *Proportion_of_waste_stream* values are in accordance with the values of the different waste operations ("wst_oper"). Waste operation "TRT" is excluded, as this refers to total values.

wst_oper	waste	geo	values	TRT_TRT_only	TRT	Proportion_of_waste_stream
DSP_L	W012	UK	36543	0	133009	0.2747408
INC	W012	UK	0	0	133009	0.0000000
RCV_E	W012	UK	0	0	133009	0.0000000
RCV_NE	W012	UK	96466	0	133009	0.7252592
TRT	W012	UK	133009	133009	133009	NA

We now calculate the *highest waste treatment proportion for each waste stream* (hwtp) across countries. We test the results by looking at the results for waste stream "W012" for non-energy recovery recycling. We can see that the highest value for *Proportion_of_waste_stream* undergoing waste treatment RCV_NE was 1 and this is reflected in the variable hwtp_prop.

wst_oper	waste	geo	values	Proportion_of_waste_stream	hwtp_prop
RCV_NE	W012	RO	17067	0.0298795	1
RCV_NE	W012	DK	1208	0.0828987	1
RCV_NE	W012	FI	18003	0.1028537	1
RCV_NE	W012	AT	12107	0.1344416	1
RCV_NE	W012	SK	4630	0.4282279	1
RCV_NE	W012	SE	67289	0.6669739	1
RCV_NE	W012	UK	96466	0.7252592	1
RCV_NE	W012	HU	14596	0.7402373	1
RCV_NE	W012	FR	171258	0.7756742	1
RCV_NE	W012	CZ	16583	0.8059781	1
RCV_NE	W012	PT	80351	0.8728491	1
RCV_NE	W012	DE	1044292	0.8934790	1

RCV_NE	W012	PL	51276	0.9189906	1
RCV_NE	W012	NL	474661	0.9722536	1
RCV_NE	W012	IT	420241	0.9722670	1
RCV_NE	W012	BE	341394	0.9816011	1
RCV_NE	W012	BG	36135	0.9839614	1
RCV_NE	W012	SI	1888	0.9931615	1
RCV_NE	W012	LT	2728	0.9985359	1
RCV_NE	W012	EE	22146	1.0000000	1
RCV_NE	W012	IE	0	NaN	1
RCV_NE	W012	LU	0	NaN	1
RCV_NE	W012	LV	0	NaN	1
RCV_NE	W012	MT	0	NaN	1

For each country, we obtain the *difference in proportion* (dprop) between the *highest recycling proportion* (hwtp_prop) across countries for each waste stream and the *actual recycling proportion value* (Proportion_of_waste_stream) for a specific country. We test the result by looking at the W12 values for the UK. We can see that the operation has worked by looking at dprop value for RCV_NE which is hwtp_prop - Proportion_of_waste_stream = 0.2747408. This is the difference between the proportion of the highest recycling performer for this waste stream and the UK. In order for the UK to catch up with the best performing country, in terms of the proportion of its W012 waste stream that gets recycled, it would need to recycle at least an additional 0.2747408 of the waste stream.

geo	waste	hwtp_prop	Proportion_of_waste_stream	dprop	wst_oper
UK	W012	0.9694378	0.2747408	NA	DSP_L
UK	W012	0.1111529	0.0000000	NA	INC
UK	W012	0.5391161	0.0000000	NA	RCV_E
UK	W012	1.0000000	0.7252592	0.2747408	RCV_NE
UK	W012	-Inf	NA	NA	TRT

We now convert the *difference in proportion* (dprop) into *difference in proportion expressed in tonnes* (dt). For this we relate the values back to *TRT* (Total waste treatment), which should be a 100 percent of each waste stream. We thus multiply the *TRT* (Total waste treatment) with the *difference in proportion* (dprop) to obtain the *difference in proportion expressed in tonnes* (dt). We test this by observing that *dt* is *TRT x dprop = 36543*.

hwtp_prop	Proportion_of_waste_stream	dprop	wst_oper	dt	TRT
0.9694378	0.2747408	NA	DSP_L	NA	133009
0.1111529	0.0000000	NA	INC	NA	133009
0.5391161	0.0000000	NA	RCV_E	NA	133009
1.0000000	0.7252592	0.2747408	RCV_NE	36543	133009
-Inf	NA	NA	TRT	NA	133009

The *difference in proportion expressed in tonnes* (dt) is not yet the value of the additional tonnes, which would be diverted from landfill if a country managed to achieve the recycling rates of the best performing country. In order to arrive at this value, we need to take into acount the amount of tonnes, which actually goes to landfill. We obtain *potentially divertible landfill tons per waste stream* (pdltpw) by comparing the size of *landfilled tonnes* (lt) with *difference in proportion expressed in tonnes* (dt). If *landfilled tonnes* (lt) is bigger than *difference in proportion expressed in tonnes* (dt), we keep dt as *sltpw*. If *landfilled tonnes* (lt) is smaller than *difference in proportion expressed in tonnes* (dt), we keep *lt* as *sltpw*.

We test for the calculation by looking at the *W012* values for France: *Potentially divertible landfill tons per waste stream* (pdltpw) equals *landfilled tonnes* (lt). While the *difference in tonnes* would be 49528 if France achieved a 100% recyling of that waste stream, it actually incinerates and recovers for energy 42784 tonnes. Only 6744 tonnes are actually landfilled. Thus, it is only those landfilled tonnes which could be diverted from landfill. *Potentially divertible landfill tons per waste stream (pdltpw) = 6744* is correct.

hwtp_prop	wst_oper	dt	TRT	lt	pdltpw	values
0.9694378	DSP_L	NA	220786	6744	NA	6744
0.1111529	INC	NA	220786	6744	NA	24541
0.5391161	RCV_E	NA	220786	6744	NA	18243
1.0000000	RCV_NE	49528	220786	6744	6744	171258
-Inf	TRT	NA	220786	6744	NA	220786

Now we would like to know how much can be saved per waste stream stream per county by diverting it from landfill, with the recycling rate of the top performers as the limit. We obtain the *landfill cost savings per waste stream per country* (lcspwspc) by multiplying landfill costs with *potentially divertible landfill tons per waste stream* (pdltpw).

We test for the calculation by looking at the *W012* values for France: *potentially divertible landfill tons per waste stream* (pdltpw) multiplied with Landfill_costs equals *landfill cost savings per waste stream per country* (lcspwspc), which is 542892.

hwtp_prop	wst_oper	pdltpw	values	Landfill_costs	lcspwspc
0.9694378	DSP_L	NA	6744	80.5	NA
0.1111529	INC	NA	24541	80.5	NA
0.5391161	RCV_E	NA	18243	80.5	NA
1.0000000	RCV_NE	6744	171258	80.5	542892
-Inf	TRT	NA	220786	80.5	NA

Let's see if we can find the same for Ireland.

hwtp_prop	wst_oper	pdltpw	values	Landfill_costs	lcspwspc
0.9694378	DSP_L	NA	0	120	NA
0.1111529	INC	NA	0	120	NA
0.5391161	RCV_E	NA	0	120	NA
1.0000000	RCV_NE	NA	0	120	NA
-Inf	TRT	NA	0	120	NA

We cannot find *lcspwspc* for W012 for Ireland, as there are no values for that waste stream, at all.

We would now like to know the *savings for each waste stream across countries* (sfewsac). For this we simply sum up *landfill cost savings per waste stream per country* (lcspwspc) across countries.

We test the calculation by looking at W012 for all countries together. We can see that *sfewsac* is the sum of *lcspwspc* across countries.

waste	sfewsac	lcspwspc	geo	wst_oper

W012	51457637	13932006.6	FI	RCV_NE
W012	51457637	13750940.0	DE	RCV_NE
W012	51457637	7408320.0	AT	RCV_NE
W012	51457637	5224489.0	SE	RCV_NE
W012	51457637	3332721.6	UK	RCV_NE
W012	51457637	2048830.6	RO	RCV_NE
W012	51457637	1739328.7	NL	RCV_NE
W012	51457637	1416240.0	IT	RCV_NE
W012	51457637	620834.5	BE	RCV_NE
W012	51457637	573627.0	DK	RCV_NE
W012	51457637	542892.0	FR	RCV_NE
W012	51457637	386129.8	PL	RCV_NE
W012	51457637	163870.0	PT	RCV_NE
W012	51457637	146720.0	HU	RCV_NE
W012	51457637	127080.0	CZ	RCV_NE
W012	51457637	41840.4	SK	RCV_NE
W012	51457637	1767.0	BG	RCV_NE
W012	51457637	0.0	EE	RCV_NE
W012	51457637	0.0	LT	RCV_NE
W012	51457637	0.0	SI	RCV_NE
W012	51457637	NA	IE	RCV_NE
W012	51457637	NA	LU	RCV_NE
W012	51457637	NA	LV	RCV_NE
W012	51457637	NA	MT	RCV_NE

Now we can have a look at the *savings for each waste stream across countries* (sfewsac).

Aggregation for Europe

We now would like to obtain the *overall savings for all waste stream across countries due to landfill diversion* (os), which can result if all countries managed to catch up with the best performers in terms of recycling, in each waste category. In order to obtain *os* we sum up *savings for each waste stream across countries* (sfewsac).

Waste type	**Waste code *(sfewsac)***	**Potential savings in EUR**
Spent solvents	W011	481394.7
Acid, alkaline or saline wastes	W012	51457637.2
Used oils	W013	1138364.5
Chemical wastes	W02A	98246931.8
Industrial effluent sludges	W032	195612460.4
Sludges and liquid wastes from waste treatment	W033	142207051.9
Health care and biological wastes	W05	13174714.2
Recyclable wastes (subtotal, W06+W07 except W077)	W06_07A	6373876.6
Metal wastes, ferrous	W061	3559740.2
Metal wastes, non-ferrous	W062	2093707.6
Metal wastes, mixed ferrous and non-ferrous	W063	784128.8
Glass wastes	W071	21925766.2
Paper and cardboard wastes	W072	847541.5
Rubber wastes	W073	1077744.2
Plastic wastes	W074	33910950.5
Wood wastes	W075	29773720.6

Waste type	Waste code *(sfewsac)*	Potential savings in EUR
Textile wastes	W076	5163875.9
Waste containing PCB	W077	838470.8
Discarded vehicles	W081	2703584.2
Batteries and accumulators wastes	W0841	3251835.8
Discarded equipment (except discarded vehicles and batteries and accumulators waste)	W08A	5180100.2
Animal and mixed food waste	W091	37069786.0
	W091_092	83914432.1
Vegetal wastes	W092	46844646.2
Animal faeces, urine and manure	W093	4686186.8
Household and similar wastes	W101	2089110677.7
Mixed and undifferentiated materials	W102	521005447.1
Sorting residues	W103	2238938773.5
Common sludges	W11	145487359.4
Mineral waste from construction and demolition	W121	2788338743.6
Combustion wastes	W124	3847968823.6
Soils	W126	12633077035.8
Dredging spoils	W127	9062608087.6
Mineral wastes from waste treatment and stabilised wastes	W128_13	1122941860.5
	W12B	37484846879.1

Example of calculations for individual countries by waste stream (UK, IE)

We would now like to know the *savings for all waste stream per countries* (sfawspc). For this we simply sum up *landfill cost savings per waste stream per country* (lcspwspc) across waste streams for each country.

We test the calculation by only looking at the UK values.

geo	sfawspc	Lcspwspc	wst_oper	waste
UK	7642871207	1368.0	RCV_NE	W011
UK	7642871207	3332721.6	RCV_NE	W012
UK	7642871207	33379.2	RCV_NE	W013
UK	7642871207	2421360.0	RCV_NE	W02A
UK	7642871207	10626168.0	RCV_NE	W032
UK	7642871207	35040499.2	RCV_NE	W033
UK	7642871207	12084189.2	RCV_NE	W05
UK	7642871207	2434128.0	RCV_NE	W06
UK	7642871207	2156606.4	RCV_NE	W061
UK	7642871207	29092.8	RCV_NE	W062
UK	7642871207	248428.8	RCV_NE	W063
UK	7642871207	7475846.4	RCV_NE	W071
UK	7642871207	470592.0	RCV_NE	W072
UK	7642871207	603014.4	RCV_NE	W073
UK	7642871207	5453363.4	RCV_NE	W074
UK	7642871207	2234764.8	RCV_NE	W075
UK	7642871207	1000920.0	RCV_NE	W076

geo	sfawspc	Lcspwspc	wst_oper	waste
UK	7642871207	0.0	RCV_NE	W077
UK	7642871207	43137.6	RCV_NE	W081
UK	7642871207	14136.0	RCV_NE	W0841
UK	7642871207	449524.8	RCV_NE	W08A
UK	7642871207	10759593.6	RCV_NE	W091
UK	7642871207	18899467.2	RCV_NE	W091_092
UK	7642871207	8139873.6	RCV_NE	W092
UK	7642871207	289924.8	RCV_NE	W093
UK	7642871207	729506155.2	RCV_NE	W101
UK	7642871207	26956440.0	RCV_NE	W102
UK	7642871207	543144486.7	RCV_NE	W103
UK	7642871207	2802849.6	RCV_NE	W11
UK	7642871207	211904287.3	RCV_NE	W121
UK	7642871207	224714702.4	RCV_NE	W124
UK	7642871207	1976323620.9	RCV_NE	W126
UK	7642871207	1150317820.8	RCV_NE	W127
UK	7642871207	214439107.2	RCV_NE	W128_13
UK	7642871207	2438519636.7	RCV_NE	W12B

Let's repeat the tests with a different country (Ireland):

geo	sfawspc	lcspwspc	wst_oper	waste
IE	506444671	0.0	RCV_NE	W011
IE	506444671	NA	RCV_NE	W012
IE	506444671	0.0	RCV_NE	W013
IE	506444671	184440.0	RCV_NE	W02A
IE	506444671	26760.0	RCV_NE	W032
IE	506444671	6817440.0	RCV_NE	W033
IE	506444671	3519.0	RCV_NE	W05
IE	506444671	5280.0	RCV_NE	W06
IE	506444671	0.0	RCV_NE	W061
IE	506444671	3720.0	RCV_NE	W062
IE	506444671	1560.0	RCV_NE	W063
IE	506444671	41280.0	RCV_NE	W071
IE	506444671	0.0	RCV_NE	W072
IE	506444671	0.0	RCV_NE	W073
IE	506444671	0.0	RCV_NE	W074
IE	506444671	0.0	RCV_NE	W075
IE	506444671	0.0	RCV_NE	W076
IE	506444671	NA	RCV_NE	W077
IE	506444671	NA	RCV_NE	W081
IE	506444671	NA	RCV_NE	W0841
IE	506444671	0.0	RCV_NE	W08A
IE	506444671	14040.0	RCV_NE	W091
IE	506444671	14520.0	RCV_NE	W091_092
IE	506444671	480.0	RCV_NE	W092
IE	506444671	3120.0	RCV_NE	W093
IE	506444671	39274300.9	RCV_NE	W101
IE	506444671	5244545.6	RCV_NE	W102
IE	506444671	25096200.0	RCV_NE	W103
IE	506444671	95566.8	RCV_NE	W11
IE	506444671	66407.4	RCV_NE	W121
IE	506444671	27578400.0	RCV_NE	W124
IE	506444671	3407660.8	RCV_NE	W126
IE	506444671	0.0	RCV_NE	W127
IE	506444671	947760.0	RCV_NE	W128_13
IE	506444671	397617670.6	RCV_NE	W12B

This analysis can be reproduced for all EU28 countries for which there is data.

Analysis of best performers in terms of recycling for each waste stream

In the following table we present the top three recyclers for each waste stream. If there more than three countries share the top three places, we still only list three countries.

Geo	Waste	Proportion of waste stream
BG	W011	1.0000000
LV	W011	1.0000000
PT	W011	0.9994898
EE	W012	1.0000000
LT	W012	0.9985359
SI	W012	0.9931615
BG	W013	1.0000000
LU	W013	1.0000000
PT	W013	0.9993020
LU	W02A	1.0000000
LV	W02A	0.9628378
LT	W02A	0.9390173
LU	W032	1.0000000
EE	W032	0.9590414
LV	W032	0.8756310
EE	W033	1.0000000
SI	W033	1.0000000
AT	W033	0.9935793
LV	W05	0.5750000
LT	W05	0.2032520
UK	W05	0.0479034
LU	W071	1.0000000
NL	W071	0.9997479
PL	W071	0.9993141
HU	W075	0.9145141
CZ	W075	0.9139127
DK	W075	0.9064897
UK	W077	0.9986679
PL	W077	0.8166667
IT	W077	0.3606557
AT	W081	1.0000000
BE	W081	1.0000000
BG	W081	1.0000000
AT	W0841	1.0000000
BE	W0841	1.0000000
EE	W0841	1.0000000
IE	W08A	1.0000000
LU	W08A	1.0000000
LV	W08A	1.0000000
LV	W102	0.9780410
SI	W102	0.9511138
PL	W102	0.7833907
LV	W103	0.6799849
CZ	W103	0.4967005
PL	W103	0.4816351
MT	W121	0.9987587
IE	W121	0.9973699
NL	W121	0.9911118
LU	W124	1.0000000
BE	W124	0.9931024
NL	W124	0.9900575
PL	W126	0.9998344
SI	W126	0.9995243
EE	W126	0.9977841
EE	W127	1.0000000
IE	W127	1.0000000
LT	W127	1.0000000
EE	W128_13	1.0000000
LV	W128_13	1.0000000
CZ	W128_13	0.9872279
MT	W12B	0.9985370
PT	W12B	0.8114833
CZ	W12B	0.8008685
EE	W06	1.0000000
LU	W06	1.0000000
SI	W06	0.9999780
EE	W061	1.0000000
FR	W061	1.0000000
IE	W061	1.0000000
EE	W062	1.0000000
LT	W062	1.0000000
LU	W062	1.0000000
EE	W063	1.0000000
LT	W063	1.0000000
LU	W063	1.0000000
IE	W072	1.0000000
LU	W072	1.0000000
SI	W072	0.9999032
EE	W073	1.0000000
IE	W073	1.0000000
BE	W073	0.9958060
IE	W074	0.9956694
LV	W074	0.9920457
BG	W074	0.9918624
BE	W076	0.9890018
DK	W076	0.9831093

Geo	Waste	Proportion of waste stream
FR	W076	0.9710000
LU	W091	1.0000000
SE	W091	0.9990879
AT	W091	0.9950938
LU	W091_092	1.0000000
AT	W091_092	0.9958143
SI	W091_092	0.9876723
LU	W092	1.0000000
SI	W092	0.9997099
AT	W092	0.9963151
LU	W093	1.0000000
SE	W093	1.0000000
SI	W093	1.0000000
IT	W101	0.6473867
PL	W101	0.3226808
RO	W101	0.1225918
LT	W11	0.9735211
LV	W11	0.9679285
IE	W11	0.9676054

Source: own calculation based on Eurostat (2017)

12. Appendix D Correlation analyses

Correlation landfill costs and landfilling

Waste	Waste Code	Cor	Pvalue
Household and similar wastes	W101	-0.7229	0.00009756
Paper and cardboard wastes	W072	-0.6542	0.000956
Mixed and undifferentiated materials	W102	-0.5749	0.004113
Animal and mixed food waste; vegetal wastes (W091+W092)	W091_092	-0.558	0.005656
Animal faeces, urine and manure	W093	-0.5489	0.008157
Vegetal wastes	W092	-0.5263	0.009879
Common sludges	W11	-0.4851	0.01627
Chemical wastes	W02A	-0.4638	0.02245
Combustion wastes	W124	-0.4706	0.02342
Rubber wastes	W073	-0.4286	0.04129
Textile wastes	W076	-0.4274	0.05329
Animal and mixed food waste	W091	-0.4048	0.05537

Discarded equipment (except discarded vehicles and batteries and accumulators waste) (W08 except W081, W0841)	W08A	-0.395	0.0621
Plastic wastes	W074	-0.3744	0.07144
Wood wastes	W075	-0.3106	0.1396
Mineral wastes from waste treatment and stabilised wastes	W128_13	-0.3102	0.1402
Industrial effluent sludges	W032	-0.2746	0.1941
Used oils	W013	-0.2818	0.2039
Sorting residues	W103	-0.2537	0.2316
Glass wastes	W071	-0.2448	0.2603
Mineral waste from construction and demolition	W121	-0.2057	0.3348
Metallic wastes (W061+W062+W063)	W06	-0.2145	0.3379
Metal wastes, mixed ferrous and non-ferrous	W063	-0.1818	0.4302
Batteries and accumulators wastes	W0841	-0.1802	0.4604
Acid, alkaline or saline wastes	W012	-0.1675	0.4802
Health care and biological wastes	W05	-0.1545	0.4924
Metal wastes, non-ferrous	W062	0.1268	0.5644
Metal wastes, ferrous	W061	0.1132	0.6071
Soils	W126	0.1065	0.6287
Waste containing PCB	W077	0.08487	0.773
Dredging spoils	W127	-0.0512	0.8303
Other mineral wastes (W122+W123+W125)	W12B	-0.03915	0.8559
Discarded vehicles	W081	0.03225	0.8957
Spent solvents	W011	0.02398	0.9135
Sludges and liquid wastes from waste treatment	W033	0.004967	0.9816

Source: authors

Correlation landfill costs and recycling

Waste	Waste Code	Cor	Pvalue
Animal and mixed food waste	W091	0.6487	0.0006062
Animal and mixed food waste; vegetal wastes (W091 + W092)	W091_092	0.5713	0.004409
Animal faeces, urine and manure	W093	0.5725	0.005359
Vegetal wastes	W092	0.4715	0.02314
Combustion wastes	W124	0.4639	0.02575
Spent solvents	W011	-0.457	0.02834
Wood wastes	W075	-0.3801	0.06691
Discarded equipment (except discarded vehicles and batteries and accumulators waste) (W08 except W081, W0841)	W08A	0.3073	0.1641
Textile wastes	W076	0.3036	0.1695
Waste containing PCB	W077	0.3641	0.2006

Discarded vehicles	W081	-0.288	0.2318
Chemical wastes	W02A	0.2365	0.2659
Mineral wastes from waste treatment and stabilised wastes	W128_13	0.2313	0.2769
Glass wastes	W071	0.2328	0.2851
Health care and biological wastes	W05	-0.2129	0.3294
Metallic wastes (W061+W062+W063)	W06	0.1992	0.3742
Mineral waste from construction and demolition	W121	0.1783	0.4044
Metal wastes, mixed ferrous and non-ferrous	W063	0.1827	0.4157
Household and similar wastes	W101	0.1436	0.5132
Metal wastes, non-ferrous	W062	-0.1269	0.5639
Metal wastes, ferrous	W061	-0.1298	0.5649
Industrial effluent sludges	W032	-0.1191	0.5792
Soils	W126	-0.1107	0.6152
Paper and cardboard wastes	W072	0.1052	0.633
Acid, alkaline or saline wastes	W012	0.1022	0.6682
Sludges and liquid wastes from waste treatment	W033	-0.08997	0.6759
Rubber wastes	W073	0.0774	0.7256
Used oils	W013	-0.07612	0.7299
Sorting residues	W103	-0.07261	0.736
Common sludges	W11	0.06406	0.7662
Mixed and undifferentiated materials	W102	0.05801	0.7926
Plastic wastes	W074	0.0493	0.819
Batteries and accumulators wastes	W0841	-0.04467	0.8517
Dredging spoils	W127	0.02144	0.9265
Other mineral wastes (W122+W123+W125)	W12B	-0.002276	0.9916

13. Appendix E Opportunities for IS by type of waste stream

Animal and mixed food waste
In Amsterdam "[o]n-site organic residual streams (including nished edible fat, animal fats and su- permarket waste) are processed for the production of biodiesel, biogas through anaerobic diges- tion and fertiliser. Chaincraft develops a technology on-site to distil components for the food and chemical industry from organic residual streams".

Batteries and accumulators wastes
We did not find that recycling or landfilling of batteries and accumulators wastes shows any sta- tistically significant correlation with landfill tax. This points to the need to find more technological rather than merely policy approaches in order to foster greater recycling. The Project Prospecting critical raw materials from e-waste (ProSUM) seeks to provide "a centralised database of all avail- able data and information on arisings, stocks, flows and treatment of [i.a.] batteries with the ability to reference all spatial and non-spatial data".

Construction waste
RE4U is a project developing prefabricated elements with a high degree of recycled materials and reused structures from demolished buildings.
VEEP "aims to enable the incorporation of higher levels of C&DW inorganic recycled materials in new concrete".
A project in the city of Hamburg aims to recycle asphalt for use in road resurfacing.
The IRCOW project aims at a) greater construction and demolition waste (CDW) recycling via on- site treatment, and b) greater construction wood reuse, and c) recycling of products containing as- bestos and mineral fibres. This is a promising technology for dealing with hazardous construction waste (W121"Mineral waste from construction and demolition").

The HISER project aims to develop: a special Building Information Systems enabling improved materials recovery, a sensor based automated sorting technology, a modernized electro-fragmentation technology, a new low-cost classification technology (ADR system) innovative recycling technologies for gypsum plasterboards, new recycling technologies for C&D waste wood and other minor emerging waste fractions, an automated quality assessment system, the use of recycled materials for the creation of lower CO2 footprint and lower em- bodied energy cements, high-quality concrete with higher incorporation levels (higher than 30%) of recycled aggregates, new green concrete recipes with slightly lower cement amounts in favour of fine re- cycled aggregates, new reinforced concrete with C&DW recovered fibers, manufacture of new bricks from CDW, use of VOC-absorbing plasterboards, fire resistant plasters and gypsum plaster- board composite panels for diverse optimized recipes and prototypes, transformation of wood CDW into Wood-plastic composites (WPCs) with increased performance and lower price, and the creation of classification system for C&DW wood fractions in order to enable market development.
The BAMB project is developing a materials passports, which should serve to increase the recy- clability and re-usability of the built environment, as well as a reversible building design for com- ponent reuse.
"A possible synergy is to use the fly ash as an input in cement production. This would reduce the amount of waste landfilled and avoid the environmental problems associated with conventional clinker production. However, fly ash contains heavy metals and this kind of synergy is not pos- sible today due to regulations. In order to use fly ash in cement production the legislation needs to change. The change could lead to economical and environmental effects, both for the cement factory and the CHP plant." http://www.industriellekologi.se/symbiosis/lidkoping.html If we assume a high degree of circularity due to industrial symbiosis and the phasing out of coal-fir- ing, we would expect a drastic reduction in combustion waste. In order to arrive at a better analysis, we should need to know what percentages consists of com- bustion waste from coal-firing and what from waste incineration. If we can assume reduced waste incinceration rates due to upstream reduction ins waste, the reduced landfill costs could form part of the market potential in monetary terms. Amongst the NACE 2 codes for the sources of different waste streams, Code D represents ener- gy generation, which allows us to account for a large part of ash from coal burning.

Slags are a type of combustion waste (Eurostat 2010, 74f.). The SPIRE - RESLAG project aims to • extract Critical Raw Materials, • generate feedstock for refractory ceramics industry from steel slag and use it as • heat storage material for waste heat recovery and • Thermal Energy Storage system feedstock for Concentrated Solar Power applications.

Combustion waste from waste collection activities
There are studies suggesting a downstream use of Municipal Solid Waste (MSW) fly ash in differ- ent applications, which could be another instance of IS. If some of these measures were used, we could assume another reduction of landfilling.
Combustion waste does not contain waste from waste incineration.
Methodology: We could take the combustion waste from waste collection etc industrial activities (E38) and ad- just all countries with higher landfilling of combustions waste to the top end of the lower quantile, to represent a radical but not extreme improvement. The saved tons can thus be deducted from landfill costs. Alternative to this methodology We could also decide to see combustion waste from coal-firing as a resource and asses the mar- ket potential. However, overall it would be desirable to phase out coal production and there are also risks involved in using fly-ash. [A Chinese study saw the risks as low http://www.sciencedirect.com/science/article/pii/S0304389408012673]

Discarded equipment
The SPIRE - REE4EU project aims to improve the recycling in-process and EoL permanent mag- nets to obtain rare earth oxide (REO) mixture.
The SPIRE - CABRISS project aims to recycle solar PV cells.
The SPIRE - ADIR project aims to improve the automated disassembly of electronic equipment to separate and recover valuable materials. This could help to improve recycling of waste streams such as discarded equipment and vehicles.
The In situ recovery of resources from waste repositories project optimize the in situ recovery of 'E-tech' elements and Elements of Value (EoV) from waste repositories.

Dredging spoils
Dredging spoils are hazardous when containing heavy metals or organic pollutants. In cases where dredging spoils are contaminated, at least these are not near waterbodies anymore, al- though there is a danger of remobilising toxic materials.
Contaminated dredging spoils can receive similiar treatments as contaminated soil.

Where there is no reason to assume that they should be contaminated, and after testing, dredging spoils can be used as materials for construction or landscaping. A better integration of local and regional building projects with dredging activity is a promising way for reducing the landfilling of dredging spoils. As they are closely located to waterbodies, the transportation of dredging spoils is less carbon intensive than that of aggregates far away from water bodies. This points to oppor- tunites for better coordinating dredging activity not only with local construction and landscaping but with that occuring, within reasonable distance, along the water body in question, potentially stretching across administrative and national borders.

Glass wastes
We have not found a significant correlation between landfill costs and waste treatment of glass. The Ellen McArthur Foundation describes a method for using glass waste as a partial cement substitute. Considering how CO2 intensive cement is, this may be an area worthy of investigation.

Household and similar wastes
We can compare countries with sophisticated household waste sorting systems and those without. If we assume that the laggards can catch up with the leaders, we can then calculate what would happen in terms of landfill costs if “Household and similar wastes” everywhere achieved a similar level as in the most advanced countries

Metal wastes, mixed ferrous and non-ferrous
The Beyond biorecovery: environmental win-win by biorefining of metallic wastes into new func- tional materials project aims to turn metallic wastes into functional nanomaterials (base metal sulfides, rare earth and uranium phosphates).

Mineral and solidified wastes
The recycling rate of mineral wastes can probably be optimised. However, due to high transporta- tion costs, the demand mineral waste from construction and demolition is likely to be rather local or regional in nature.

Stabilised wastes
Waste with Code W128_13(“Mineral wastes from waste treatment and stabilised wastes”), Min- eral wastes from waste treatment and stabilised wastes (Items 50 and 51) is made up of “Mineral wastes from waste treatment” and “Solidified, stabilised and vitrified wastes”.
“Kind of waste: Bottom ash and slag from waste incineration and pyrolysis Fly ashes and other wastes from flue gas treatment in waste incineration plants Solidified, stabilised and vitrified wastes from waste treatment Origin: Incineration or pyrolysis of waste Waste treatment Hazardous: When containing organic pollutants, heavy metals “

W121(“Mineral waste from construction and demolition”)
W12B(“Other mineral wastes (W122+W123+W125)”)
Methods for transforming asbestos into less toxic materials could help to avoid landfilling it.

Mixed and undifferentiated materials
Sorting residues
Sorting residues come mainly from waste treatment processes. When sorting residues contain heavy metals or organic pollutants, e.g. oil, they can be hazardous.
Sorting residues are partly sourced from waste water treatment plants (Eurostat 2010, 63). In the famous case of IS in Kalundborg, “sludge is utilised at A/S Bioteknisk Jordrens Soilrem^ [Website www.soilrem.dk cannot be found ..] as a nutrient in the bio-remediation process” http://www.veks. dk/en/focus/district-heating-industrial
In Amsterdam dry sewage sludge is fermented to produce biogas.
In Friesland technologies are being developed for turning sewage sludges into into biopolymers and for using them in asphalt.

Soils
According to the company Soilutions “the result of the landfill tax escalator has been the develop- ment of soil treatment centres across the UK, facilities which treat your waste soils at prices which are generally much less than landfill.”
Reasons for soil contamination, which should be the primary reasons for landfill soil, should be strictly reduced in the future, as soil should be taken better care of.
It is very difficult to say anything generally about how industrial symbiosis can alleviate costs from landfilling soils. The contamination of soils may have reasons stretching long back into history. Where higher landfill prices stimulate the uptake of soil decontamination practices, it would be difficult to argue that decontaminating instead of landfilling soils would save the amount of money currently charged for landfilling. Potentially, the price of landfilling would need to rise first, or the price of decontamination decrease, in order to induce the decontamination.
Decontamination of soils offers huge market opportunities for the development of dedicated tech- nologies are other countrie such as China suffer from many contaminated sites. The development of such technologies could put Europe in an advantageous position in this potentially growing market and be an attractive side effect of cleaning up its own soils and savings costs on landfilling.
“RGS 90 A/S is treating 250.000 tons of oil and chem ical polluted soil in their facility in Kalundborg. RGS 90 A/S is using sludge from the Central WWTP as nutrie nt to the bio-remediation process.” http://www.ewp.rpi.edu/hartford/~stephc/ET/Other/Miscellaneous/Kalundborg-Industrial%20Sym-biosis%20Institue.pdf
“Bioteknisk Jordrens - a soil remediation company that joined the Symbiosis in 1998.” http://www.iisbe.org/iisbe/gbpn/documents/policies/instruments/UNEP-green-ind-zones/UNEP-GIZ-ppt-kalundborg%20case.pdf
JRC on Soil Contamination http://esdac.jrc.ec.europa.eu/themes/soil-contamination

Soils
Belgium has mandatory soil screening and clean-up when land is bought and sold, which has enhanced its capacities to monitor and improve soils. This is likely to have resulted in a number of patents for soil decontamination, putting Belgium as the leader in this technology in Europe, when measured by patents per capita.

Textile wastes
The SPIRE - RESYNTEX project aims to recycle unwearable textile waste for use in the textile and chemical industries. It also aims to use waste from • clothing and household textiles, • uniforms, and • mattresses. It seeks to extract protein from wool and silk fibres and produce ethanol from cotton fibres. It also seeks to recycle synthetic polyamide and PET.
The Reblend: Transforming Post-consumer Textile Waste Into High Quality Products project aims to recycle post consumer garments. The Post-Consumer Recycled Denim Standard aims to devel- oping a preferred industry buying standard for Post-Consumer Recycled Denim.
The Fibersort machine is a “a technology that automatically sorts large volumes of mixed post consumer textiles by fiber type. Once sorted, these materials become reliable, consistent input materials for high value textile to textile recyclers”.

Vegetal wastes
Zero Waste Scotland describes a project seeking to utilise food processing residues in paint, coat- ings, and concrete.
Another project in Amsterdam dedicates itself to the extraction of fruit and vegetable fractions from waste for further processing into proteins, bio-oil and hydrogen.
Another project in Amsterdam dedicates itself to the utilisation of grass clippings and organic res- idues in order to produce biofuels.

Wood wastes
The SPIRE - REHAP project aims to better utilise agricultural and forestry waste.
The SPIRE - SteamBio projects aims to put agro-forestry residues to biochemical and bioenergy uses.

14. APPENDIX F BIBLIOGRAPHY

Ashton, W. (2008). Understanding the organization of industrial ecosystems: A social network approach. Journal of Industrial Ecology, 12(1), 34–51. https://doi.org/10.1111/j.1530-9290.2008.00002.x

Baas, L. W., & Boons, F. A. (2004). An industrial ecology project in practice: Exploring the boundaries of decision-making levels in regional industrial systems, Journal of Cleaner Production, 12(8–10), 1073–1085. https://doi.org/10.1016/j.jclepro.2004.02.005

Baas, L., & Boons, F. (2007). Industrial Symbiosis in a social science perspective. In Industrial Symbiosis in Action. Report on the Third International Industrial Symbiosis Research Symposium Birmingham, England, August 5-6, 2006 (pp. 77–82). BOOK.

Baas, L. (2011). Planning and uncovering industrial symbiosis: Comparing the Rotterdam and Östergötland regions. Business Strategy and the Environment, 20(7), 428–440. https://doi.org/10.1002/bse.735

Behera, S. K., Kim, J. H., Lee, S. Y., Suh, S., & Park, H. S. (2012). Evolution of "designed" industrial symbiosis networks in the Ulsan Eco-industrial Park: "Research and development into business" as the enabling framework, Journal of Cleaner Production, 29–30: 103–112. https://doi.org/10.1016/j.jclepro.2012.02.009

Bilsen, V., Pieterjan, D., Kristof, K. T., Ilse, L., Lars, M., Dirk, N., … Jurgen, V. (2015). Analysis of certain waste streams and the potential of Industrial Symbiosis to promote waste as a resource for EU Industry. Interim report 13rd of November 2014. https://doi.org/10.2873/689189

Boons, F., & Howard-Grenville, J. (2009). The social embeddedness of industrial ecology. BOOKTI - The Social Embeddedness of Industrial Ecology, Cheltenham, UK. https://doi.org/http://dx.doi.org/10.4337/9781848449060

CEMBUREAU (2016) Cement, concrete & the circular economy, available online at: https://cembureau.eu/media/1229/9062_cembureau_cementconcretecirculareconomy_coprocessing_2016-09-01-04.pdf

Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. Annual Review of Energy Environment, 25(1), 313–337. https://doi.org/doi:10.1146/annurev.energy.25.1.313

Chertow, M. R. (2007). "Uncovering" Industrial Symbiosis. Journal of Industrial Ecology, 11(1). https://doi.org/10.1162/jiec.2007.1110

Chertow, M. R., & Lombardi, R. (2005). Policy Analysis Quantifying Economic and Environmental Benefits of Co-Located Firms. Environmental Science & Technology, 39(17), 6535–6541. https://doi.org/10.1021/es050050+

Chertow, M. and Lombardi, R. (2005). Quantifying economic and environmental benefits of co-located firms. Environmental Science and Technology, 39-17, 6535-6541. http://pubs.acs.org/doi/abs/10.1021/es050050+

Chertow, M., & Ehrenfeld, J. (2012). Organizing Self-Organizing Systems: Toward a Theory of Industrial Symbiosis. Journal of Industrial Ecology, 16(1), 13–27. https://doi.org/10.1111/j.1530-9290.2011.00450.x

Costa, I., Massard, G., & Agarwal, A. (2010). Waste management policies for industrial symbiosis development: case studies in European countries. Journal of Cleaner Production, 18(8), 815–822. https://doi.org/10.1016/j.jclepro.2009.12.019

Côté, R. P., & Cohen-Rosenthal, E. (1998). Designing eco-industrial parks: a synthesis of some experiences. Journal of Cleaner Production, 6(3–4), 181–188. https://doi.org/10.1016/S0959-6526(98)00029-8

COWI (2011). Economic analysis of resource efficiency policies. A study commissioned by DG Environment

Cucciella, F., et al (2015) Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, vol 51, Nov 2015, pp263-272

Daddi, T., Nucci, B., & Iraldo, F. (2017). Using Life Cycle Assessment (LCA) to measure the environmental benefits of industrial symbiosis in an industrial cluster of SMEs. Journal of Cleaner Production, 147, 157–164. https://doi.org/10.1016/j.jclepro.2017.01.090

Desrochers, P. (2004). Industrial symbiosis: The case for market coordination. Journal of Cleaner Production, 12(8–10), 1099–1110. https://doi.org/10.1016/j.jclepro.2004.02.008

Domenech, T. (2010). Social aspects of industrial symbiosis networks, PhD, available at: http://discovery.ucl.ac.uk/762629/

Domenech, T., & Davies, M. (2010). The role of Embeddedness in Industrial Symbiosis Networks: Phases in the Evolution of Industrial Symbiosis Networks. Business Strategy and the Environment, 20(5), 281–296. https://doi.org/10.1002/bse.695

Domenech, T., & Davies, M. (2011). Structure and morphology of industrial symbiosis networks: The case of Kalundborg. Procedia - Social and Behavioral Sciences, 10, 79–89. https://doi.org/10.1016/j.sbspro.2011.01.011

DTI, Ecorys, REC, 2013. Treating Waste as a Resource for the EU Industry. Analysis of Various Waste Streams and the Competitiveness of their Client Industries

Gong, L., Gu, F., Fujita, T., Hayasashi, Y. Gao, J. (2014). Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects in China. Energy Policy, 65, 388-397. https://www.sciencedirect.com/science/article/pii/S0301421513010410

ECSIP (2013) Treating Waste as a Resource for EU Industry: Analysis of various waste streams and the competitiveness of their client industries Available at: https://ec.europa.eu/docsroom/documents/3866/attachments/1/translations/en/renditions/native

ECORYS (2014). Critical raw materials for the transition to a 100% sustainable energy future, available online at: http://awsassets.panda.org/downloads/critical_materials_report___jan_2014_lr.pdf

EEA (2013). Managing municipal solid waste — A review of achievements in 32 European countries, EEA Report No 2/2013, European Environment Agency.

EIB, 2015: Access to finance conditions for projects supporting circular economy, Dec 2015 http://www.eib.org/attachments/pj/access_to_finance_study_on_circular_economy_en.pdf

Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment (2015) Growth Within: A Circular Economy Vision for a Competitive Europe

European Commission (2011). Communication on Roadmap to a Resource Efficient Europe. COM/2011/0571 final

European Commission, (2015): Communication on Closing the loop - An EU action plan for the Circular Economy COM/2015/0614 final

EC, 2016, Study on assessing the environmental fiscal reform potential for the EU-28(http://ec.europa.eu/environment/integration/green_semester/pdf/Eunomia%20EFR%20Final%20Report%20MAIN%20REPORT.pdf).

European Commission, 2017: Circular Economy Action Plan Implementation Report (COM(2017) 33 final), http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

EC (2017). EU Construction and Demolition waste protocol, available online at https://ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en

Eurostat (2017) 'Waste database generation of waste' (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en), last accessed January 2018.

European Cluster Observatory, 2015: Foresight report on industrial and cluster opportunities, https://ec.europa.eu/docsroom/documents/16264/attachments/1/translations/en/renditions/native

European Cluster Observatory, 2017: Priority Sector Report, Circular Economy, https://ec.europa.eu/docsroom/documents/24681/attachments/3/translations/en/renditions/native

Ehrenfeld, J., & Gertler, N. (1997). Industrial Ecology in Practice: The Evolution of Interdependence at Kalundborg. Journal of Industrial Ecology, 1(1), 67–79. https://doi.org/10.1162/jiec.1997.1.1.67

Granoveter, M. (1985). Economic action and social structure: The problem of embeddedness. American Journal of Sociology, 91(3), 481–511. https://doi.org/10.1086/228311

Ihobe. (2016). 36 Circular economy demonstration projects in the Basque country. Results from business initiatives.

Jacobsen, N. B. (2006). Industrial symbiosis in Kalundborg, Denmark. Journal of Industrial Ecology, 10(1), 239–255. https://doi.org/10.1162/108819806775545411

Jensen, P. D. (2016). The role of geospatial industrial diversity in the facilitation of regional industrial symbiosis. Resources, Conservation and Recycling, 107, 92–103. https://doi.org/10.1016/j.resconrec.2015.11.018

Jensen, P. D., Basson, L., Hellawell, E. E., Bailey, M. R., & Leach, M. (2011). Quantifying "geographic proximity": Experiences from the United Kingdom's National Industrial Symbiosis Programme. Resources, Conservation and Recycling, 55(7), 703–712. https://doi.org/10.1016/j.resconrec.2011.02.003

Johnsen, I., Berlina, A. Lindberg, G. (Ed.). The potential of industrial symbiosis as a key driver for green growth in the Nordic regions, available online at: http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A875756&dswid=9944

Karlsoon, M. and Wolf, A. (2008). Using an optimization model to evaluate the economic benefits of industrial symbiosis in the forest industry. Journal of Cleaner Production, 16 (14), 1536-1544. https://doi.org/10.1016/j.jclepro.2007.08.017

Kemp, R., Dijk, M., Domenech, T. (2013). Synthsis report and conclusions about barriers and drivers for resource efficiency, POLFREE_policy Options for a Resource Efficient Economy in Europe, funded by the EC under grant agreement 308371, nD1.7, University College London: London (UK).

La Marca, F. (2015): Treatment and recovery of plants in materials recovery supply chains, in Mancuso, E., & Luciano, A (2015): Experiences of Industrial Symbiosis in Italy. Proceedings of conferences promoted by ENEA at Ecomondo in 2012, 2013, 2014.

Lehtoranta, S., Nissinen, A., Mattila, T., & Melanen, M. (2011). Industrial symbiosis and the policy instruments of sustainable consumption and production. Journal of Cleaner Production, 19(16), 1865–1875. https://doi.org/10.1016/j.jclepro.2011.04.002

Lombardi, D. R., & Laybourn, P. (2012). Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries. Journal of Industrial Ecology, 16(1), 28–37. https://doi.org/10.1111/j.1530-9290.2011.00444.x

Lowe, E. A., & Evans, L. K. (1995). Industrial ecology and industrial ecosystems. Journal of Cleaner Production, 3(1–2), 47–53. https://doi.org/10.1016/0959-6526(95)00045-G

Martin, M., Svensson, N., Fonseca, J., Eklund, M. (2014). Quantifying environmental performance of integrated bioethanol and biogas production. Renewable Energy, 61, 109-116. https://www.sciencedirect.com/science/article/pii/S0960148112006581

Mazzucato, M. (2016). From market fixing to market-creating: a new framework for innovation policy. Industry and Innovation, 23(2), 140–156. https://doi.org/10.1080/13662716.2016.1146124

Mitchell, P., & James, K. (2015). Economic Growth Potential of More Circular Economies. https://doi.org/10.13140/RG.2.1.1026.5049

Nordregio, Johnsen, I. H. G., Berlina, A., Lindberg, G., Mikkola, N., Olsen, L. S., & Teräs, J. (2015). The potential of industrial symbiosis as a key driver of green growth in Nordic regions. Retrieved from http://www.nordregio.se/en/Publications/Publications-2015/The-potential-of-industrial-symbiosis-as-a-key-driver-of-green-growth-in-Nordic-regions/

Paquin, R. L., & Howard-Grenville, J. (2009). Facilitating Regional Industrial Symbiosis: Network Growth in the UK's National Industrial Symbiosis Programme. The Social Embeddedness of Industrial Ecology, 103–127. https://doi.org/10.1111/j.1530-9290.2011.00437.x

Paquin, R. L., & Howard-Grenville, J. (2011). The Evolution of Facilitated Industrial Symbiosis. Journal of Industrial Ecology, 16(1), 83–93. https://doi.org/10.1111/j.1530-9290.2011.00437.x

Pellenbarg, P. H. (2002). Sustainable business sites in the netherlands: a review *. Journal of Environmental Planning and Management, 45(1), 59–84. https://doi.org/10.1080/0964056012010019

Posch, A. (2010). Industrial Recycling Networks as Starting Points for Broader Sustainability-Oriented Cooperation? Journal of Industrial Ecology, 14(2), 242–257. https://doi.org/10.1111/j.1530-9290.2010.00231.x

Schmiegelow, A. and Andersen, M. (2016). Absorptive Capacity and Industrial Symbiosis – Experiences from the Danish Green Industrial Symbiosis SME Program 2013-2015, EU-SPRI Conference Lund 2016, available online at: http://orbit.dtu.dk/ws/files/124307931/Absorptive_Capacity_and_Industrial_Symbiosis.pdf

Schwarz, E. J., & Steininger, K. W. (1997). Implementing nature's lesson: the industrial recycling network enhancing regional development. Journal of Cleaner Production Cleaner Production, 5(12), 47–56. https://doi.org/10.1016/S0959-6526(97)00009-7

Sitra (2013) : Arvoa ainekierroista – teollisten symbioosien globaali markkinakatsaus. Commissioned from Gaia Consulting, authored by Aho, M. et al ; in Johnsen (2016), p. 33.

Sokka, L., Lehtoranta, S., Nissinen, A., & Melanen, M. (2011). Analyzing the Environmental Benefits of Industrial Symbiosis: Life Cycle Assessment Applied to a Finnish Forest Industry Complex. Journal of Industrial Ecology, 15(1), 137–155. https://doi.org/10.1111/j.1530-9290.2010.00276.x

Daddi, T., Iraldo, F., Frey, M., Gallo, P., Gianfrate, V., 2016. Regional policies and eco-industrial development: the voluntary environmental certification scheme of the eco-industrial parks in Tuscany (Italy). J. Clean. Prod. 114, 62-70.

Technopolis Group, Wuppertal Institute, Thinkstep, Fraunhofer ISI (2016): Regulatory barriers to the circular economy. Lessons from ten case studies. https://ec.europa.eu/growth/content/regulatory-barriers-circular-economy-lessons-ten-case-studies-1_en

Tudor, T., Adam, E., & Bates, M. (2007). Drivers and limitations for the successful development and functioning of EIPs (eco-industrial parks): A literature review. Ecological Economics, 61, 199–207. https://doi.org/10.1016/j.ecolecon.2006.10.010

Uzzi, B. (1996). The Sources and Consequences of Embeddedness for the Economic Performance of Organizations: The Network Effect. American Sociological Review. https://doi.org/10.2307/2096399

Van Berkel, R. (2006). Regional resource synergies for sustainable development in heavy industrial areas: an overview of opportunities and experiences. Perth, WA, Australia: Curtin University of Technology, (1), 139.

Van Berkel, R. (2010). Quantifying sustainability benefits of industrial symbioses. Journal of Cleaner Production, 14(3), 371-373.

Velenturf, A., Purnell, P. (2017). Resource Recovery from Waste: Restoring the Balance between Resource Scarcity and Waste Overload. Sustainability, 9(9), 1163. http://dx.doi.org/10.3390/su9091603

Wilts, H., Gries, N. von, Bahn-Walkowiak, B., O`Brien, M., Busemann, J., Domenech, T., Bleischwitz, R., Dijk, M. (2015). Policy Mixes for Resource Efficiency (POLFREE - Policy Options for a Resource efficient Economy; Project funded by the European Commission under Grant 308371 No. D2.3). University College London (UCL), London.

WRAP, (2015): The Quality Protocols, http://www.wrapcymru.org.uk/content/quality-protocols

Wolf, A. Eklund, M., Söderström, M. (2007). Developing integration in a local industrial ecosystem - an explorative approach. Business Strategy and the Environment, 16 (2007), 442-455

Wolf, A., & Petersson, K. (2007). Industrial symbiosis in the Swedish forest industry. Progress in Industrial Ecology, an International Journal, 4(5), 348–362. JOUR. https://doi.org/10.1504/PIE.2007.015616

HOW TO OBTAIN EU PUBLICATIONS

Free publications:

- one copy:

via EU Bookshop (http://bookshop.europa.eu);

- more than one copy or posters/maps:

from the European Union's representations (http://ec.europa.eu/represent_en.htm);
from the delegations in non-EU countries (http://eeas.europa.eu/delegations/index_en.htm);
by contacting the Europe Direct service (http://europa.eu/europedirect/index_en.htm) or calling 00 800 6 7 8 9 10 11 (freephone number from anywhere in the EU) (*).

(*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you).

Priced publications:

- via EU Bookshop (http://bookshop.europa.eu).

Priced subscriptions:

- via one of the sales agents of the Publications Office of the European Union (http://publications.europa.eu/others/agents/index_en.htm).

Catalogue number
ET-05-17-150-EN-N

Publications Office

doi:number 10.2873/346873