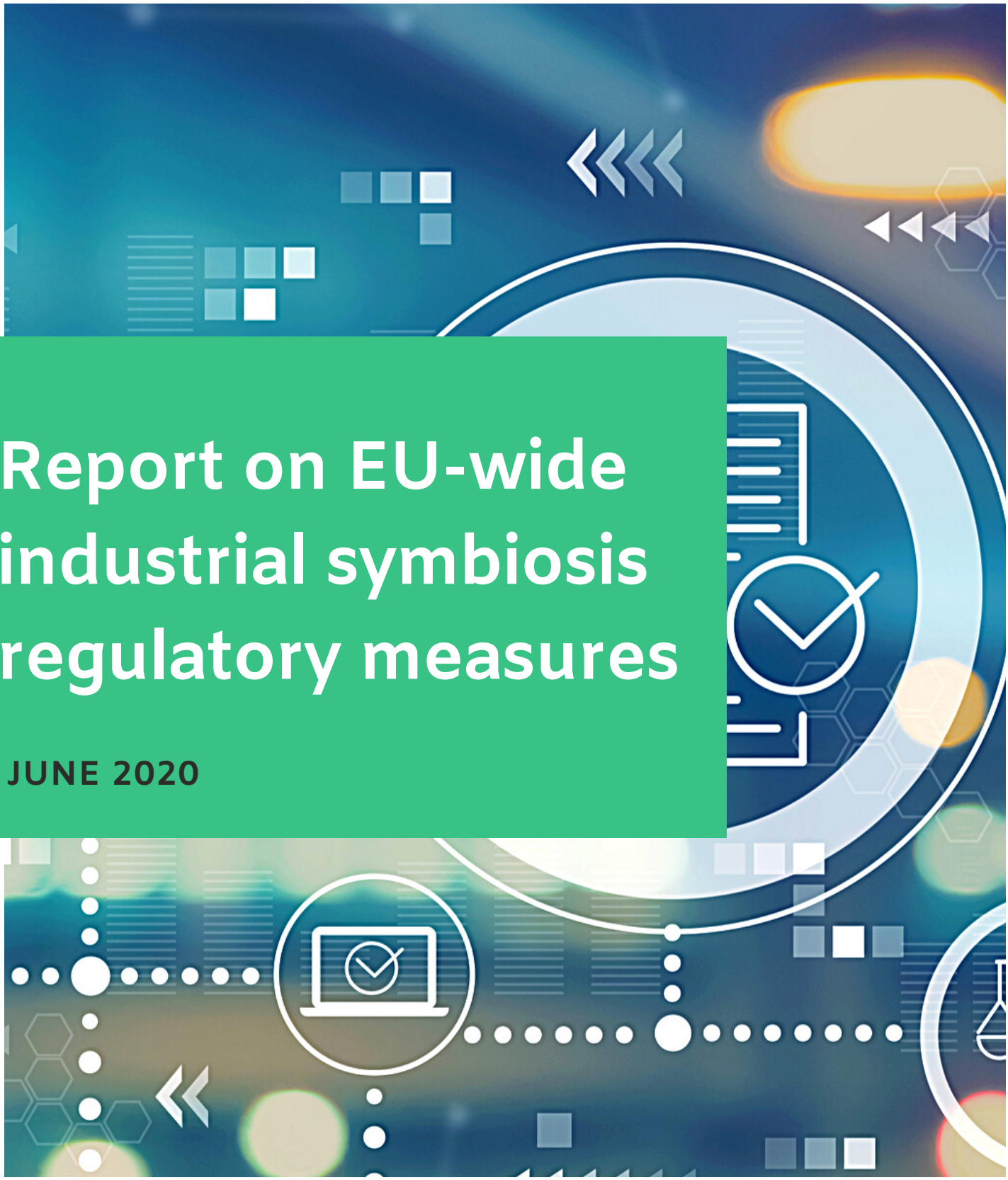

Report on EU-wide industrial symbiosis regulatory measures

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Deliverable 4.4

Report on EU-wide IS regulatory measures, regulatory gaps and need for IS deployment

WP4 - Action Plan for Industrial Symbiosis in Europe

T4.4 - Policy Advice & Standardisation

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Figures and tables

Executive Summary

This report provides an overview and analysis of EU policies related to the uptake of Industrial Symbiosis and resource efficiency in the industrial process sector, providing recommendations to European policy makers on required future focus and action.

This is the result of work carried out in the Work Package 4 Action Plan for Industrial Symbiosis in Europe of the SCALER project, that aims to increase the uptake of industrial symbiosis across Europe. Under the European Union's Horizon 2020 initiative, the project has developed a set of best practices, tools and guidelines, helping businesses and industrial sites and policy makers support the scaling of IS practices across the European territory. This research was based on all outcomes and activities undertaken within the project, as well as desktop research on the latest EU policies and related material.

This report displays:

- Overview of the current policy framework that has been adopted at European level and is either directly or indirectly linked to industrial symbiosis in the process industry
- Gaps and Recommendations for the EU policy framework
- Conclusions

1. Introduction

According to historical demographers, by 1800 the global population was around 1 billion people, and has increased to 7.7 billion to date. The rapid growth of population in the last two centuries has come with environmental stress and degradation, a result of increased demand and waste of resources to secure food, clothing, shelter, comfort and recreation. Such damages are reflected in the loss of biodiversity, increase of greenhouse gas emissions, rise of deforestation, stratospheric ozone depletion, acid rain, loss of topsoil, and shortages of water, food, and fuel-wood in many parts of the world (The National Academies of Sciences 1993). Such impact on ecosystems has been intensified by consumption habits and behaviours, technology, and resource management, and the future threats will be even more challenging with an expected population of 9.7 billion by 2050 and even 10.9 billion by 2100.

Together with population growth, industrial activities have rapidly increased in both high and low-income countries, intensifying the consumption rates of finite resources and energy, globally. The concern of some scientists is that "such growth would reach a level that would overwhelm the capacity of the earth and its resources to generate the food and other goods needed for human life" (Peterson 2017). According to the publication in the World Economic Forum, the experience of scarcity on a short- to medium-term basis, is real and often felt directly by businesses and consumers, as it has been faced by electronics and other manufacturing with rare earth minerals and metals, for example (D'Esposito 2012). However, such (risk of) scarcity and depletion of resources and energy for process industries can be prevented and/or mitigated through sustainable and efficient management, supported by a shift to renewable raw materials, recycling and reusing waste streams and energy, and innovating with more sustainable materials and products. In other words, it can be significatively overcome by putting *Industrial Symbiosis* in practice.

The concept of Industrial Symbiosis is tracked back to 1940, under the term 'industrial ecosystems' (still used nowadays). However, in 1989 this concept was strongly established as a field of scientific research with the article written by Frosch and Gallopoulos (1989), who defined this concept as "the consumption of energy and materials [that] is optimized and [where] the effluents of one process [...] serve as the raw material for another process". In the same year that this article was published, a self-organized cluster of companies from different industries, originated in 1961, that replicated the industrial ecosystem theory was uncovered in Kalundborg, Denmark (Figure 1) (Frosch and Gallopoulos 1989).

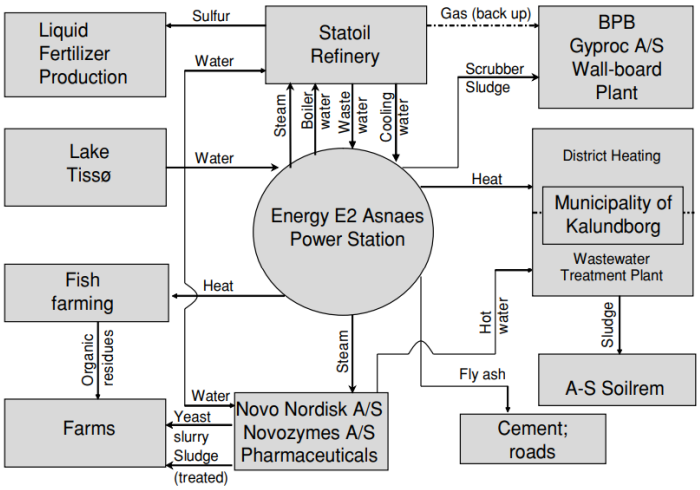

Figure 1 - Industrial symbiosis of Kalundborg, Denmark

According to Chertow's (2000) definition, "Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity". Thus, Industrial Symbiosis creates loops of technical or biological materials, while minimising the leakage and waste in such loops, and leverages underutilised resources. Such transactions may be based on reducing and reusing waste and by-products, finding innovative ways to source inputs and upgrade the value of waste and residuals by providing resource and energy saving alternatives to traditional management or recycling options (Artola et al. 2018). The Sustainable Process Industry through Resources and Energy Efficiency (SPIRE) illustrates, in Figure 2Figure 2, the concept of a cross-sectorial target driven energy and resource efficiency and competitiveness programme for the process industry.

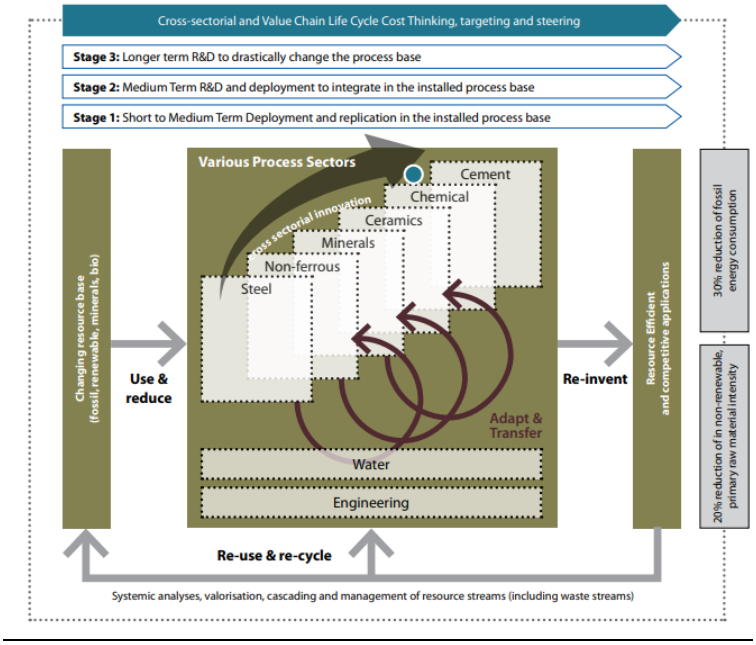

Figure 2 - The SPIRE concept: a cross-sectorial target driven resource efficiency and competitiveness programme for the process industry

Based on the report of the European Commission *"Cooperation fostering industrial symbiosis: market potential, good practice and policy actions (2018)*", there are five drivers to move towards Industrial Symbiosis (IS): economic and business impact, eco-innovation, regional economic development, resource security, energy security and climate change mitigation. Taking all these elements into account, Industrial Symbiosis has been recognised as a key approach to deliver circular economy at a local scale, while reducing waste, emissions, costs and primary resources demand, and promoting collaborative economics. Some of these benefits are captured by the life cycle assessment (LCA), commissioned in 2015 by Kalundborg Symbiosis, which showed that connecting the enterprises saves more than 24 million EUR on the bottom line annually, while the socio-economic benefit amounts to more than 14 million EUR. On the other hand, the symbiosis leads to an emission reduction of about 635,000 tonnes of CO2 equivalents. Such numbers express that interconnected industries leverage their competitive power, while the public sector is able to save money, by reducing investments in waste management, for example (Fundation (n.d.))

Frosch and Gallopoulos (1989) highlighted the importance of changing corporate and public attitudes to favour the ecosystem (or 'symbiosis') approach, and government regulations must promote innovative waste-minimization schemes, focus on the economic incentives for sustainable manufacturing, sound technology and allowance for technological change, encourage (or at least not discourage) the development of alternative processes and

innovate methods for dealing with industrial by-products, take advantage of industry's technological know-how so as to avoid counterproductive control measures. Building such framework, would be possible only if there is a collaboration along government, industry and environmental groups.

It is now evident that Industrial Symbiosis relates to the transformation of the current system of industrial production to a new, low-emission and resource efficient paradigm. This will require a 'systems approach', focusing on many levers around the system that are required for its transformation and are complementary to each other: from new technologies and skills, to citizen participation and behaviour change, to new business models supported by innovative finance, policies and regulatory frameworks.

1 Methodology

The methodology pursued for the collection and compilation of the analysis presented in this deliverable is based on desktop research, supported by the use of the Publications Office of the EU, Science Direct, Google Scholar and Google search engines which give access to relevant articles and publications relevant to Industrial Symbiosis. Other open online databases that include resources were consulted as well, according to the needs for the proper development of this work.

Additionally, this deliverable builds on the findings identified in SCALER Work Packages 2 & 3, whereby a systematic literature review, case study analysis and stakeholder consultation have been undertaken. Hence, the approach taken for the compilation of the following findings was to seek to complement existing literature reviews and analysis pieces with the findings coming out of SCALER project.

The evolution of this analysis was split into three main consecutive stages. The first stage of this work required the collection and analyses of EU Policies that are relevant to Industrial Symbiosis with a holistic approach aiming to cover the various elements of the production system (such as skills, business models, digital technology and sustainable finance) and applicable to the process industry.

Based on the data collected in the first step, the information was analysed with the method of the literature review. This included the outcomes of the SCALER deliverables to complement the outcomes. Finally, an approach of comparing and contrasting and indexing the European policies was developed so as to identify and articulate the gaps and recommendations described in this deliverable documents.

2 Barriers and key enablers for Industrial Symbiosis

For many years main industrial processes have been following a rather linear resource consumption model that is energy demanding and emissions intensive. The transition to a net-zero carbon world remains the major challenge of our century. Carbon neutrality programmes as progressively adopted by the EU member states demand structural changes in all pillars of the economy and society. Industry will then need to transform dramatically in order to reduce its greenhouse gas (GHG) emissions and hence contribute to keeping the global temperatures to a well below two degrees Celsius in order to avoid catastrophic impacts of Climate Change (UNFCC 2020).

Industrial symbiosis has been widely recognised as the approach which "closes the loop in the material and energy flows contributing to a circular economy model [...] and represents a shift from the traditional industrial model in which wastes are considered the norm, to integrated systems in which everything has its use" (Kallay and Szuppinger 2017).

This chapter aims to give a concise overview of relevant IS trends, barriers and enablers, that will then lend to the policy analysis space to understand if these measures at the European level are adequate enough to enhance or enable a more robust sustainable production system. Although not exhaustive, this overview seeks to show whether current IS activities are normally part of regulations and strategies, for example the recently published EU Circular Economy and the EU Industrial Strategy. Industry in the EU represents one of the main pillars of its economy, which is still energy and resource-intensive, which is putting additional pressure on our planet's resources and contributes significantly to climate change (Wyns 2017).

The European Council (EC) has acknowledged the importance and the urgency to take action and part in the battle of climate change and the ultimate need to take immediate steps in order to meet the ambitions set by the Paris Agreement. To this extent, the EC has set the objectives that define the design of policies fit for that purpose and that will be discouraging a GHG intensive emissions future (EUCO 9/19 2019). The ambition has been clearly formulated and industries and scientists emphasise on the need for a strong policy framework to allow a transition to climate neutrality and this could be more effectively achieved with innovation (Wyns et. al. 2019).

The transition to a more sustainable production and less emission-intensive system, and a more circular and resource-efficient economy could be facilitated by IS. This is also based on three pillars that will help the system move from a more linear model (which is the predominant one) to a more circular approach (which is a very complex one). As highlighted in (Taranic et al. 2016) Circular Economy is articulated around three pillars: "1) environmental benefits, particularly in terms of reduced impacts and reduced resource

usage; 2) cost savings from reduced natural resource needs; and 3) the creation of new markets, providing additional economic benefits of circular economy practices, e.g. in terms of jobs creation or wealth creation". Therefore, IS underpins a huge potential for stakeholders to unlock powerful tools, systems and processes that promote sustainable development.

SCALER has been working extensively via the numerous Work Packages and the associated deliverables developed to identify the challenges and the lever points for the uptake of IS by taking also a systemic approach (Vladimirova et al. 2018).

In literature, there are numerous success factors and barriers discussed that hinder the uptake of industrial symbiosis. A study from FISSAC examined more than 60 Industrial Symbiosis projects and concluded on the types of barriers that have been widely identified: (1) the sustainable development and its three pillars, namely the environment, economic and social; (2) culture, trust, information and collaboration; (3) technological and regulations (Kirchherr et al. 2018; Bonnet et al. 2016; Artola et al. 2018).

SCALER Deliverable 2.2 "Lessons learnt and best practices for enhancing industrial symbiosis in the process industry" (Vladimirova et al. 2018) presents a thorough analysis of the barriers, grouped and summarised in Table 1.

KEY BARRIERS	DESCRIPTION
Materials	"In some instances, the current waste market is not sufficiently developed on both the demand and supply sides, and there is an insufficient amount of wastes as substitutes" ((Vladimirova et al. 2018).
Technology and Data	Technology plays a critical role in the implementations and advancing of IS and in the cases "where this is missing or there are shortfalls in infrastructure readiness, sustainable by-product exchanges become more difficult" and in addition "the paucity or poor quality of data on waste" hinder the uptake of IS (ibid. p.23).
Legal and regulatory	Regulations and Directives can be a barrier to the IS implementation as they can be either rigid or absent from the current regulatory framework. Additionally, there might be legal barriers (e.g. IP) in the waste exchange process which in fact the provokes in the way specific material can be recycled, reused basted on legislation. Finally, this is even more hindered by the fact that industries to obtain approvals for waste reuse will necessitate to go through the intermediaries and regulatory authorities and hence this will impede the potential synergies (ibid. p.23).

Policies to incentivise	Policy plays a significant role in fostering resource efficiency through IS." Government policies to incentivise initiatives of IS are also needed (e.g., tax relief) as well as to regulate IS, particularly at the level of industrial parks. More broadly, there is a lack of funding to promote IS and disseminate information" (ibid. p.24).
Information	Lack of information and knowledge of possible processes, material and by-product exchanges constitutes a barrier in IS. This is even more reinforced by the lack of data regarding the multiple waste streams and industrial waste material (to also include water and energy requirements). This reluctance to sharing information across industrial actors results in a limited sharing of resources, and as information is a scarce resource is often seen as a detriment to progress (ibid. 24).
Coordination and management and leadership support	Institutional support is of high importance for the IS. If this support is absent there is little synergetic activity across the industrial communities and networks. In eco-industrial parks this will necessitate that IS will be integrated into their management practices and leadership will always need to support it (ibid, p. 25).
Skill shortages	Through effective community management and awareness leadership would be expected to enhance the training offer to people unaware of or lack sufficient expertise of IS concepts and benefits. Also, there is a consistent element in literature highlighting the lack of policies to enable educational programmes for stakeholders (ibid, p. 25).
Business as usual	Changing existing practices is often impeding the IS. Innovation and Entrepreneurship would be a way to overcome this by suggesting new business models that at their core foresee symbiotic relationships. Such new mindsets surrounding and encompassing the IS rather finding it as a distraction to the processes would be needed to be diverted so as to alter this approach of "business as usual" (ibid, p. 25).
Economic and operational	Time is a critical element in assessing the positive effects of IS. IS requires a significant amount of time to perceive the gains or have an actual return on the initial investment. This also in relation to a constant lack of external financial support can hinder the IS. In addition, the high costs to acquire the initial infrastructure to create the circumstances for enabling the IS do constitute an extra element to the problematic (ibid, p. 25).

Over planning	"Over planning rather than allowing spontaneous interactions is highlighted as a hindrance to engendering relationships between firms" (ibid, p. 26).
Trust and risk	Firms in this traditional modus operandi compete to each other and thus they remain inaccessible to further their cooperation. They do not have trust in sharing information, and this resonates with the fact there is a constant focus on business as usual. To turn waste into a resource is technologically feasible what firms often lack is trust, Finally, the potential systemic failure is a risk which is an extra danger of cascading in a symbiotic system. Also, the risk in terms of environmental burden due to dangerous waste leakages and the associated increased economic risks are perceived as hindrances to the IS deployment, since they are integrated in tight legal frameworks across the world (ibid, p. 26).

Table 1. Barriers for industrial symbiosis

The main barriers to achieving potential industrial symbiosis are very diverse but at the same time interconnected, as illustrated in Table 1. To overcome those barriers and achieve further dissemination of industrial symbiosis requires concerted and orchestrated action at various levels. The SCALER Project, during its implementation and along the research conducted, has promoted drivers that can be strong ingredients to initiate synergies across industries and thus overcome any hurdles, halts or delays to further the development of different benefits that can come from industrial symbiosis relationships (SCALER 2020b).

KEY DRIVERS TO START SYNERGIES	DESCRIPTION
Tools	Tools and indicators play an important role in helping companies find potential synergies with others. These can range from online waste markets, to systems that help identify synergies at a geographical or sectorial level. **Matchmaking** A variety of tools have been developed, where companies can input information on their processes and waste streams into a database accessible to others. **Waste and synergy value** A main benefit of industrial symbiosis is the added value it can bring to companies, through the recovery and reuse of materials. But embarking on the process can be difficult without visibility on future savings, both in

	terms of materials and related costs. Some tools can help assess the value in waste streams and thus support planning. **Impact assessments** Quantifying the environmental impacts of a synergy is important for several reasons e.g. it can provide transparency to investors and government bodies, generate data to monitor specific targets, etc.
Technology	Emerging technologies like big data, modelling and Internet of Things enable IS. Recycling technologies, for example, can enable new synergy opportunities – but technology is also helping consolidate and track data points that can support the search for resource sharing at big scale.
Finance	Implementing resource synergies can result in increased income through the sale of new by-products, or savings on raw materials and processes (transportation, waste management, etc.) – but financial gains can also be made via direct incentives, often governmental (1) tax incentives like tax relief; (2) investments supporting resource exchanges, reuse and recycling of waste; (3) subsidies for the development of waste exchange networks and projects can also be a way to deliver financial support to companies.
Intermediaries	Intermediaries, also known as knowledge brokers or coordinating bodies, can provide managerial, financial, and regulatory support to firms. As coordinating "neutral players" they help to facilitate communication and cooperation among parties and provide a knowledge conduit between industrial clusters.
Networks	Promoting long term partnerships and knowledge sharing is essential to the development of wider scale industrial resource sharing. When starting off, looking into all the elements of exchanging waste and resources with other industries can seem daunting – but networks exist to accompany actors in their mission, share knowledge and best practices, and provide access to potential collaboration opportunities.
Knowledge and Skills	Access to the right knowledge can be key in starting a synergy - not only in terms of information, but also to build confidence. Moreover, lasting synergies require a specific set of skills that will support the sustainability of

	the collaboration. Below are a few key highlights and considerations to consider when looking into education and skills to support industrial symbiosis implementation.

Table 2. Drivers of industrial symbiosis

Arguably in literature Industrial Symbiosis (IS) can emerge through top-down or bottom-up processes and has mainly been seen as an innovative model to achieve a circular and a more resource-efficient economy due to its use of waste from one industry to become a resource for another.

Its multiple benefits to the economy, environment and society are countless. Through IS we can achieve a sustainable future which is often hindered by multiple interrelated barriers. Top-down processes require governments, and the EU, to provide the necessary regulatory framework and policies that will be flexible and thus not strict and/or prescriptive so that they will enable and facilitate the uptake of IS, and unveil new opportunities to valorise waste resources in a synergetic way.

Global competition will accelerate this change as global players, such as China, are progressively orientating their efforts to expand their industrial base and are focusing on technologies and strategic value chains.

There is a growing body of literature that also concentrates on the evolution of IS and eco-industrial parks as the main drivers to boost economic growth. There is no doubt that further effort will need to be invested to ensure that the benefits of IS be evenly distributed, for example reskilling and capacity building. Policies will be needed to manage potential adverse effects as well as to highlight the advantages of implementing IS networks.

3 Overview of EU Policies

An effort to collect the EU policies that directly or indirectly enable industrial symbiosis in the process industry, a list of specific sectors (defined by the SPIRE), were assembled to support the research(please see Annex 1). The elements considered to make industrial symbiosis possible are based on sustainable operations that include innovative and efficient use of materials and energy, reuse and recycle of waste streams, pioneering design of sustainable products, together with the support of digital transformation technologies and sustainable finance instruments.

Over the collection of more than 50 documents related to EU Relations, Directives, Commission Communications, EU Bodies' Opinions & Referrals, IS EU Best Practices and EU Strategies, the distribution of policies focus is evident. Related statistics help identify where

the main attention has been given and where potential gaps could be. Policies identified relate to the efficient resource use in the industry sectors e.g. Chemical industry, with substantial focus on plastics. Also, the review has focused on the Engineering sector, in the way of electronics (Figure 1).

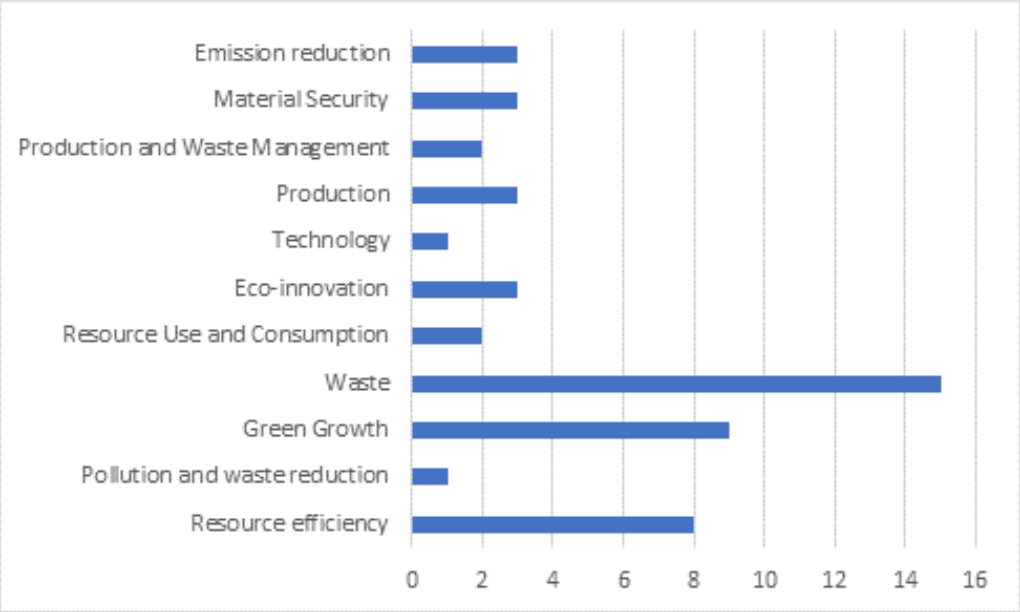

Figure 3. Distribution of Industrial Symbiosis policies per theme

The quantitative analysis of the policies collected also shows that the majority have an impact on National, European and Global level ('Macro'), but there are also some policies focusing on eco-industrial parks or regional development frameworks ('Meso') (**Error! R eference source not found.**3 and see also Table 3).

LEVEL	DESCRIPTION	EXAMPLES
Macro	• Global • European • National	The majority of the policies that have been developed are at EU level, such as EU Directives & Regulations e.g. EU Waste Framework Directive, REACH, Circular Economy Package, Industrial Strategy, etc.

Meso	• Industrial Parks (IPs), Eco-Industrial Parks (EIPs) • Regional	Few policies – information based on best practices (UK NISP), government stimulation of CE/IS integration in EIPs *NB: in this Deliverable we focus more on EU-level policies*
Micro	• Individual firms • local	Lack of policies - Crucial role of facilitating entities – not specific policies but specific actors that influence policies e.g. intermediaries providing services to facilitate IS over brokering, exchange platforms open market services, etc.

Table 3. Policy distribution across different levels of implementation

3.1 Policy framework in Europe

In the dawn of the new millennium IS gradually becomes widely recognised and accepted as an approach through which the energy-intensive industrial sectors (such as steel, chemicals and cement) can achieve sustainability, be a circular and prosperous green industry, and form the structures for achieving shared prosperity and resilience. There is a growing number of researchers who have been working on industrial symbiosis subjects. The success of policies designed for IS implementation ex-novo are often questioned, and there are arguments that policy should promote existing clusters or nurture existing symbiotic structures, so as to succeed in developing them further.

Three policy strategies or ideas have been put forward to be considered from policymakers, governments and businesses "1. bring to light kernels of cooperative activity that are still hidden; 2. assist the kernels that are taking shape; and 3. provide incentives to catalyse new kernels by identifying "precursors to symbiosis" (Chertow 2007). Hence, policy could become a significant force to promote existing symbiotic synergies, especially when these have emerged from a bottom-up approach.

In literature, it has been also pointed out that "in the early years of the twenty-first century, industrial symbiosis became a widely accepted and strategically prioritised policy tool in the context of a green economy. There is a wide consensus that industrial symbiosis holds huge

potential to make a significant contribution to improved resource efficiency and increased innovation and that it is a key element in establishing circular economies." (Kusch 2015).

The EU has been supporting IS indirectly or directly for more than 30 years. However, this support becomes more and more intense in the first decade of the twenty-first century (Figure 4). With the launch of the Roadmap for a Resource Efficient Europe, which is embedded in the Resource Efficiency Flagship Initiative, the EU is recognising IS as a core element (Kusch 2015). Over the past decade, the European Commission (EC) has adopted a variety of ambitious policies, e.g. its 'Circular Economy Package' (launched in 2015 and later updated in 2020) with a focus on closing the loop of product lifecycles through greater re-use and recycling (European Commission, 2015, 2018; Lazarevic and Valve, 2017).

The EU strategies and policies often see IS as an increasingly prominent tool at the EU level to deliver on The Paris Agreement (UNFCC 2020). Figure 4 shows the evolution of policies and legislation over the past 20 years to promote IS (Milios 2018). The potential of IS to contribute to the sustainable production systems and the effectiveness of EU industry is well recognised through the Roadmap to a Resource Efficient Europe, which highlights the importance of the reuse of the raw materials and that the industries could have direct economic benefits from saving on resources and sales ("1.4bn EUR a year and generate 1.6bn EUR in sales" (European Commission 2011d). At the same time IS is proposed to be a lever for more efficient production and thus the EU could facilitate the industries to collaborate and make good use of the waste and the by-products by exploiting the potential of the IS (Kallay and Szuppinger 2017). The EU supports directly or indirectly the IS as an integral part of policies relevant to the economy and the environment. This was further improved with the launch of the most pertinent policies such as "Manifesto for a Resource Efficient Europe" setting targets for a systemic change in the use of resources in the economy and suggested the pathways towards circularity with innovation, investments and regulations (European Commission 2011c; Johnsen 2015). Hereafter, the EU continues to support IS initiatives via strategic documents such as the Europe 2020 strategy, the update of the Waste Framework Directive, the launch of the Resource Efficiency Flagship Initiative (which admits that resource efficiency is plausible via the realisation of IS), the Circular Economy Action Plan and the Industrial Strategy also have influenced the embeddedness of IS in policy strategies to achieve the targets and objectives set in the Europe 2020 Strategy.. In addition multiple European communications have highlighted the value of the IS and more specifically in 2012 it was stipulated that "factories will use highly energy- and material-efficient processes, employ renewable and recycled materials, and increasingly adopt sustainable business models such as industrial symbiosis to recover materials and dissipated heat and energy" (European Commission 2012a).

Figure 4. EU Policies relevant to IS – Timeline

[As adapted and updated from (Milios 2018)]

Policies play a crucial role in Europe, by creating the enabling factors and paths to a high performing and resource efficient European Industry. The EU policy agenda is broad and is covering a wide range of instruments that spread across innovation, green growth, and economic development. IS has been recognised in the EU as key policy tool to force the EU industries become sustainable (European Commission 2012a). The programmes and the initiatives of the EU do indeed signal a clear direction to future political support of IS. The EU has enacted a significant number of strategies, regulations, and directives aiming to minimise the impact of industries and companies on the environment with innovation and sustainability being at the heart of the spirit of such ambitions. In practice the EU has recognized this through setting in the EU's waste legislation, chemical policy and eco-design directive and measures (Johnsen 2015).

Even though the EU has been regulating and orchestrating the IS policies, has also directed Member States to develop their own mechanisms and frameworks. However, the EU Member States often report a constrained implementation of their plans with regards to circular economy national action plans, and subsequently industrial symbiosis is largely absent from national policy agendas, especially in the EU countries where there is limited or non-evident IS activities (Johnsen 2015; Nordregio Magazine 2016). Nevertheless, in the 2012 European Resource Efficiency Platform (EREP) it is stipulated that the "EU and Member States should foster industrial symbiosis by promoting a pan-European network of industrial

symbiosis initiatives, under which facilitators could be connected to allow match-making, including across borders and beyond the EU" (EREP 2013).

The Directorate-General (DG) for Enterprise and Industry had launched a strategy document named "Sustainable industry: Going for growth and resource efficiency", which promotes IS as a policy instrument for realizing growth and the potential of sustainable European industries. This report also notes that "IS has added value in encouraging local and regional growth particularly" (Johnsen 2015) and mentions "Kalundborg as a practical example of industrial symbiosis underpinning local and regional growth. This document is important for its connection to the growth agenda" (Lombardi et al. 2017).

The changes required to support IS are embraced by The European Commission, through the launch of *The European Green Deal* (Figure 5), on December 11, 2019. This strategy aims to "transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. At the same time, this transition must be just and inclusive." (European Commission, 2019).

Figure 5. The European Green Deal

To deliver *The European Green Deal* and achieving a climate neutral and circular economy requires the transformation of the industrial sector, and all the value chains. European industry sector remains too dependent on a throughput of new materials extracted, traded and processed into goods, and finally disposed of as waste or emissions. Only 11% of the materials it uses come from recycling (Eurostat, n.d.). Therefore, the Commission adopted

on March 10th, 2020, the *New Industrial Strategy for Europe*, that addresses the needs of industry to become greener, more circular and more digital, while remaining competitive on the global stage. Such transition 'will be supported by a new focus on industrial ecosystems, taking into account all players within a value chain … from the smallest start-ups to the largest companies, from academia to research, service providers to suppliers' (European Commission 2020a).

In addition, the introduction of *A New Circular Economy Action Plan,* will help modernise Europe's economy and draw benefit from the opportunities of the circular economy along all sectors, by ensuring that resources used are kept in the EU economy for as long as possible; stimulating the development of lead markets for climate neutral and circular products, services and business models, locally and globally; transforming consumption patterns, so that no waste is produced in the first place; encouraging businesses to offer, and to allow consumers to choose, reusable, durable and repairable products (European Commission 2020b).

The circular economy action plan will include a 'sustainable products' policy to support the circular design of all products, ensure that products placed on the EU market are designed to last longer (through restricting Single-use, tackling premature obsolescence and banning the destruction of unsold durable goods), are easier to reuse, repair and recycle. Also, to strength extended producer responsibility, by prioritising reduction and reuse of materials before recycling them, incorporating as much as possible recycled material instead of primary raw material, and supported by a single market for secondary raw materials and by-products. Furthermore, action will focus especially on resource-intensive sectors such as textiles, construction, electronics and plastics, based on plans and initiatives developed with the close involvement of the business and stakeholder community (European Commission, 2019).

Along the objectives of the Green Deal in many different sectors, digital transformation is a key enabler for reaching them. This include technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things, that would support the acceleration and maximisation of the impact of regulatory and non-regulatory efforts, aimed to adapt and mitigate climate change and protect the environment (European Commission 2019a).

Nevertheless, the success in achieving the ambition goals of the Green Deal, demands the consistent use of all policy levers: regulation and standardisation, investment and innovation, national reforms, dialogue with social partners and international cooperation. This will be a main challenge, as at the moment "there is no comprehensive set of requirements to ensure that all products placed on the EU market become increasingly sustainable and stand the test of circularity" (European Commission 2020b).

It is demanded a framework that aims to incentivise the industry to revolutionise the way how the sector designs, makes, uses and gets rid of things, while reducing environmental impacts, alleviating competition for scarce resources and reducing production costs. Such context would favour the conditions to address system and market failures, eliminating persisting barriers and creating incentives for companies to engage in IS.

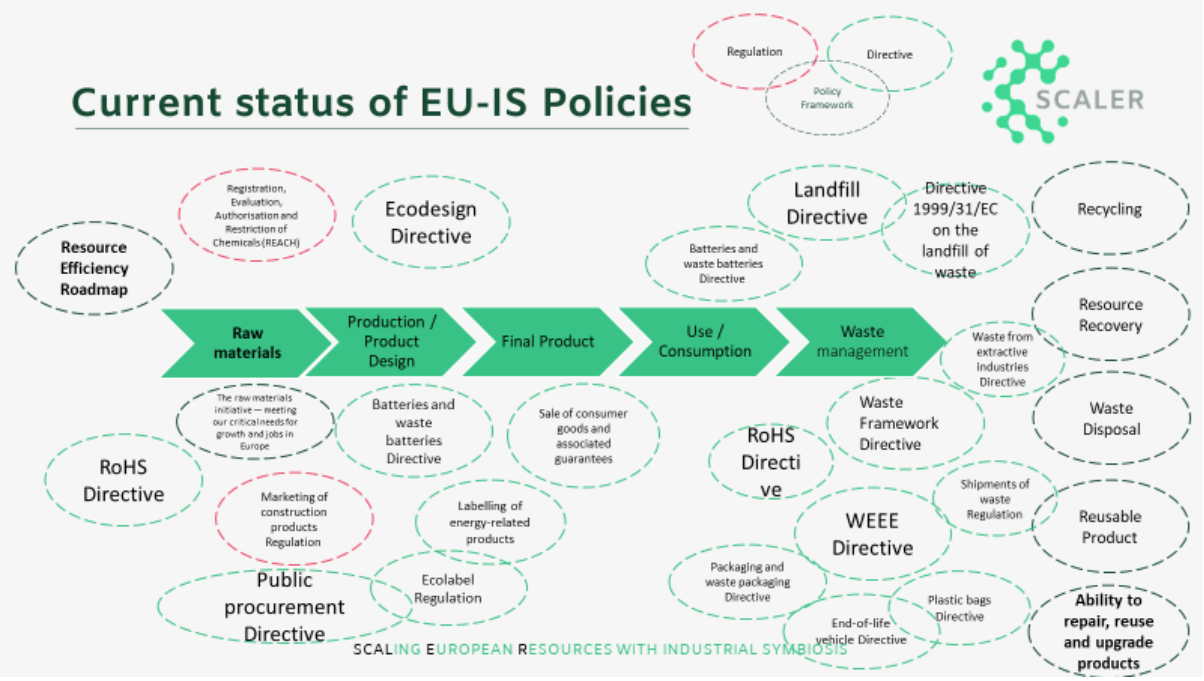

Figure 6. Mapping of EU Policies linked to Industrial Symbiosis

Despite the fact that it has been advocated that practical instruments to support the implementation of policies and regulatory frameworks -that also include measures and strategies to promote IS- are generally under-developed in the EU (Lehtoranta et al. 2011); it is observed, however, that the most critical policies regarding the resource efficiency at the EU have proposed strong objectives and are giving great incentives for the uptake of the IS. At the EU level there are regulatory frameworks and policy strategies from regulating the vehicle dismantling being more environmental friendly through waste material reuse, recycle and recovery (European Commission 2000) to the Circular Economy Action Plan that encourages to foster innovative industrial processes and industrial symbiosis is one of them that can help CE be realised. Of course, there are and there will always be gaps and challenges that one cannot neglect. Yet the EU Member States at the national and regional level have been also extensively working on developing the necessary environment in order to strengthen the economic and regulatory instruments to be seamlessly enacted, and thus adopted by the local industries and companies (Interreg Europe 2017).

According to the report of *Cooperation Fostering for Industrial Symbiosis*, published by the European Commission (2018, p. 96) there are many types of policy instruments that promote industrial symbiosis and are grouped below:

"**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 standards and metrics for IS facilitation activities"

In the following sections, there are presented a few but the most important policies that have been adopted at the EU level and have indirectly or directly facilitated, defined and promoted the IS in practice within the EU landscape and some of which are presented in the following sub-sections (Lombardi et al. 2017; International Synergies Ltd. and IFKA 2014).

3.1.1 Waste Framework Directive

The EU Waste Framework Directive (WFD) establishes the overarching legislative and regulatory framework with regards to waste management and support the efficient use of industrial waste and by-products and this legislation is compelling more firms across all industries to focus on symbiotic initiatives (Vladimirova et al. 2018). WFD sets out a comprehensive process that describes "when the waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products" (European Commission 2019b).

Not only is the WFD underlining the benefits of improving the efficiency of waste management and acknowledging that waste can become a resource, but also recognises the fundamental role of IS to realise and thus achieve the main environmental, economic, and social benefits our societies desperately seek, if IS would be put into practice. Finally, the Directive encourages all EU Member States to take enough and bold steps to facilitate it (Neves et al. 2019b). Therefore, it lays down waste management binding principles and sets out the targets for recycling by making the EU member states to establish waste management plans and waste prevention programmes (EU 2010).

The amended WFD has explicitly stated IS and has urged the MS for replicability where possible:

"In order to promote sustainable use of resources and industrial symbiosis, Member States should take appropriate measures to facilitate the recognition as a by-product of a substance or an object resulting from a production process the primary aim of which is not the production of that substance or object if the harmonised conditions established at Union level are respected. The Commission should be empowered to adopt implementing acts in order to establish detailed criteria on the application of the by-product status, prioritising replicable practices of industrial symbiosis" (EU 2010; European Commission 2018a).

3.1.2 Landfill Directive

The EU Landfill Directive (1999/31/EC) aims to prevent or reduce the adverse effects of the landfill of waste on the environment. It defines the different acceptable categories of waste and also defines wastes which are not to be accepted in any landfill and sets up a system of operating permits for landfill sites (EU 2018).

The EU Member States have introduced instruments such as landfill bans, applying taxes and charges consistent with the waste hierarchy towards managing waste more effectively and efficiently and the EU WFD has been the main driver and IS could play an important role in reducing the amount of residential and commercial urban waste that goes to landfill as well.

This Directive has "created better conditions for the recycling markets by optimally using legal and economic instruments and applying the producer responsibility concept to various waste streams [...] and led to a progressive internalisation of the waste management costs into the price of products and services" (European Commission 2005, 2011b). Thus, the EU has been targeting at creating an ambitious path for waste management and recycling and through its actions has progressed in building the necessary credibility to ensure effective implementation on achieving reduction targets.

Landfill taxes

Landfill tax has been enacted across some of the EU countries with the aim to prevent the landfilling option for waste disposal and hence promote waste minimization, reuse and recycling. Tax rates vary and are based on the waste characteristics in line with the waste hierarchy as for example inert or inactive waste generally incurs a lower charge (Lombardi et al. 2017).

Landfill tax across the EU varies dramatically in 2017 24 EU Member States have a landfill tax whilst 4 EU Member States do not have a landfill tax (CEWEP 2020, 2017) Where the landfill taxes have been implemented and by introducing an increase on to the relative costs of landfilling this would incentivise industries and companies to proceed towards a more symbiotic operation.

Landfill bans

Lombardi et.al. (2017, p. 10) argue that "landfill bans are introduced to incentivize innovation, identify new uses or processes for existing waste streams so that the waste streams are no longer generated. Landfill bans also create incentives for material substitution and industrial symbiosis".

Studies have also highlighted that there are numerous waste resources ending up in landfills and their dynamics and potential remain unleashed. In this sense IS could be a potential solution to not allow for waste disposal by landfill or incineration and thus work towards the reuse of the waste as a secondary raw material in the production processes. Therefore, there can be both economic and environmental savings, which can be also coupled with societal benefits, thus contributing to the design of a more sustainable world that operates within the planetary boundaries (Salomone et al. 2020) (European Council 2013).

In 2013, the EU presented the results of the consultation on the Review of European Waste Management Targets via the official launch of the Waste Target Review. This consultation seeks to review key targets under the Waste Framework Directive, the Landfill Directive and the Packaging and Packaging Waste Directive. The basis for the review of the targets is twofold: "to respond to the review clauses set out in the Directives, and to bring these targets in line with the Commission's ambitions of promoting resource efficiency and reducing greenhouse gas emissions" (Hogg et al. 2013). The consultation closed down in September 2013 and the Commission assessed the impacts of options that emerged from the first phase. These impacts assessed using the waste model that is being developed in parallel to this project.

3.1.3 Waste electrical and electronic equipment (WEEE)

The Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) established a framework for setting the regulations in the WEEE sector waste management by setting out the minimum requirements for the management of end-of-life products and thus encouraged the development of industrial symbiosis mechanisms. The purpose of this Directive is to "contribute to sustainable production and consumption by, as a first priority, the prevention of WEEE and, in addition, by the re-use, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste and to contribute to the efficient use of resources and the retrieval of valuable secondary raw materials" (EU 2012a).

The Directive 2002/95/EC aims at "reducing hazardous substances contained in new EEE, hazardous substances such as mercury, cadmium, lead, hexavalent chromium and polychlorinated biphenyls (PCBs) and ozone-depleting substances will still be present in WEEE for many years. The content of hazardous components in EEE is a major concern during the waste management phase, and recycling of WEEE is not undertaken to a sufficient extent. A lack of recycling results in the loss of valuable resources". It has been explored in literature the effectiveness of the WEEE Directive to promote IS, as well as establishing innovative approaches towards linking or creating a platform dedicated to the WEEE sector and subsequently to favour the creation of industrial symbiosis opportunities (Marconi et al. 2018; Galanakis 2019).

3.1.4 7th EAP

After the final assessment of the Sixth (6th) Community Environment Action Programme (EAP) that concluded in 2012 and its valuable contribution to shaping up a set of

environmental policies the programme delivered, the 7th EAP will "help to achieve the environment and climate change targets on which the Union has already agreed and to identify policy gaps where additional targets may be required" (European Council 2013).

The 7th EAP identifies three key objectives:

- to protect, conserve and enhance the Union's natural capital
- to turn the Union into a resource-efficient, green, and competitive low-carbon economy
- to safeguard the Union's citizens from environment-related pressures and risks to health and wellbeing" (European Commission 2014b).

Even though the 7th EAP does not explicitly refer to IS per se, yet via its key objectives this programme to target on resource efficiency and promoting the sustainability of the EU cities, as well as the waste management, foster recycling and re-use and ways to prevent waste, to link incineration to non-recyclable material and non-recoverable waste and finally setting the targets regarding waste policy across the EU Members.

3.1.5 European Initiative on Raw Materials

In 2008, the Commission started building the strategy to secure access to raw materials, from both primary and secondary sources, and thus adopted the raw materials initiative "which set out a strategy for tackling the issue of access to raw materials in the EU.

This strategy has 3 pillars which aim to ensure

- Fair and sustainable supply of raw materials from global markets
- Sustainable supply of raw materials within the EU
- Resource efficiency and supply of 'secondary raw b materials' through recycling" (European Commission 2008c).

Recovery and recycling as terms resonate with the approach of IS, as IS is taking place when one industry is using the waste of another instead of raw materials. In fact, materials used in the EU industrial process come from secondary or recycled sources and this is the essence of the IS concept. By using recycled materials in production lines, it is less energy-intensive than producing goods from raw virgin materials. Finally, a strong aspect to help the EU Industry turn into IS business models is that this initiative has also regulated how waste may be traded (EU 2014).

3.1.6 Resource Efficiency Flagship

Europe has been actively supporting IS initiatives and moves towards establishing the frameworks under which IS will be flourishing or create those conditions that IS could thrive. In the Europe 2020 strategy it is stipulated a vision for a "smart, sustainable and inclusive

Europe", and the flagship initiative for "A resource-efficient Europe" is launched, building at the same time on the earlier manifesto by the EC and EREP (European Council 2013).

EREP in fact has been supporting the IS development by referring to "Industrial symbiosis networks have proven successful not only in diverting waste from landfill but also in contributing to the preservation of resources and moving waste up the value chain. They have also been an accelerator of innovation and the creation of green jobs. The EU and the Member States should foster industrial symbiosis by promoting a pan-European network of industrial symbiosis initiatives, under which facilitators could be connected to allow matchmaking, including across borders and beyond the EU. The potential for creating new, or scaling up existing, networks should be exploited and a platform for knowledge exchange established. This would help companies to source inputs and to get value from their residues" (EREP 2013)

The EU Flagship Initiative "Resource Efficient Europe" was launched to pave the way towards a resource-efficient, low-carbon economy to achieve sustainable growth by finding new ways to reduce inputs and minimise the impact on the environment by reducing waste and using industrial symbiosis to increase efficient production processes. In the Roadmap to a Resource Efficient Europe, IS's potential role in boosting efficient and sustainable production is further supported and its benefits are clearly recognised and highlighted: "1. Improving the re-use of raw materials through greater 'industrial symbiosis' (where the waste of some firms is used as a resource for others) across the EU could save €1.4bn a year and generate €1.6bn in sales and 2. Help companies work together to make the best use of the waste and by-products they produce (e.g. by exploiting industrial symbiosis) " (European Commission 2011d). IS can constitute an essential tool in supporting the realisation of the targets on resource-efficiency set in the Roadmap for moving to a competitive low carbon economy in 2050.

3.1.7 Circular Economy Action Plan

In July 2014 the EU had adopted its Circular Economy Package, which described that circular systems are prominent to eliminate waste by using products in a circular way beyond their end-of-life. The Commission decided to withdraw and present later on in 2015 a new European Circular Economy Package that would enable the shift to a resource-efficient society and sustainable recycling industry across Europe.

In addition to setting out an action plan, the CE Package resulted in substantial revisions of many key EU waste legislation setting enough targets so as to avoid, re-use and recycle waste in the future. The CE Package had included suggestions for amendments or revisions to the EU Landfill Directive (1999/31/EC), the EU Waste Framework Directive (2008/98/EC), the Packaging and Packaging Waste Directive (94/62/EC), the End of Life Vehicles Directive (2000/53/EC), the Batteries Directive (2006/66/EC) and the Directive on Waste Electrical and Electronic Equipment (2012/19/EC).

On 11. March 2020 the European Commission adopted a new Circular Economy Action Plan that constitutes a building block building of the European Green Deal. In this Action Plan IS

is reported and the Commission has recognised the IS in the production processes important and calls for "facilitating industrial symbiosis by developing an industry-led reporting and certification system, and enabling the implementation of industrial symbiosis" (European Commission 2020b).

3.1.8 Industrial Emissions Directive

With the launch and enacting the Industrial Emissions Directive (IED), which entered into force on 6 January 2011, the EU has created an instrument to regulate and mitigate impacts of the EU industry on the environment. Member States based on IED adopt a coherent approach in the process of permitting or setting the operational framework for industrial installations. Since IS is seen as a prominent industrial process, which highlights the importance of the wastes or by-products of an industry become inputs (i.e. the raw materials) for another, the EU takes multiple steps forward towards meeting its circular economy objectives.

IED involves an "exemption framework to facilitate businesses processing small volumes of low-risk waste. This removes a significant cost and resource barrier for industry: the requirement of applying for a permit and the associated annual fees" (Lombardi et al. 2017) however this is challenged and questioned in other studies and thus proposed to "economy objectives can be integrated in the IED to a greater degree [...] (*by*) providing greater flexibility for industrial symbiosis" (Ricardo Energy & Environment 2019). Finally, IED has been seen as a barrier to IS as if a company decides to perform a specific action with regards to their waste management then based on its permits, this particular action cannot be revised (Lombardi et al. 2017).

3.1.9 Research and Innovation Strategy for Smart Specialisation (RIS3)

Innovation is deep inside the EU policy agenda. The EU Commission has broadly encouraged the design of national/regional research and innovation strategies for smart specialisation as a means to deliver a more targeted Structural Fund support and a strategic and integrated approach to harness the potential for smart growth and the knowledge economy in all regions.

"National/regional research and innovation strategies for smart specialisation (RIS3) are integrated, place-based economic transformation agendas that do five important things:

1. They focus on policy support and investments on key national/regional priorities, challenges and needs for knowledge-based development, including ICT-related measures

2. They build on each country's/region's strengths, competitive advantages, and potential for
   excellence.
3. They support technological as well as practice-based innovation and aim to stimulate private
   sector investment.
4. They get stakeholders fully involved and encourage innovation and experimentation.
5. They are evidence-based and include sound monitoring and evaluation systems." (European Commission 2012b)

In the RIS3 innovation is not only perceived as technological but also as innovative business processes and models such as Industrial symbiosis. This pioneering concept of IS connects distinct industries through facilitation and supports them to divert wasted by-products and resources again into the economy. Waste management and IS are both strongly interconnected and RIS3 policies favour the innovation and entrepreneurial discoveries regarding waste use from being disposed to being productively and value-added used elsewhere in the economic system, thus enhancing resource efficiency and promoting the green economy.

3.1.10 Eco-design Directive

The EU had launched the Integrate Product Policy and Eco-design with its COM (2003) 302 that aimed primarily" to reduce the environmental impacts from products throughout their life-cycle, harnessing, where possible, a market driven approach, within which competitiveness concerns are integrated" (European Commission 2003). The eco-design directive had been revised in 2009 as "Energy-related products account for a large proportion of the consumption of natural resources and energy in the Community" and this Directive "establishes a framework for the setting of Community eco-design requirements for energy-related products with the aim of ensuring the free movement of such products within the internal market" (EU 2009). Under these terms IS can contribute to realising the aims of the Eco-design as it could improve the performance of a product at the very beginning start of its life cycle, since it can be created with the use of another industry's waste or by-products, and then at its end-of-life it could be re-integrated into the production.

3.1.11 Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

The Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) entered into force on 1st June 2007 (EU 2006). This regulation has harmonised the regulatory framework around the chemicals process in the EU by introducing a coherent and single management system.

"In principle, REACH applies to all chemical substances; not only those used in industrial processes but also in our day-to-day lives, for example in cleaning products, paints as well as in articles such as clothes, furniture and electrical appliances. Therefore, the regulation has an impact on most companies across the EU.

REACH places the burden of proof on companies. To comply with the regulation, companies must identify and manage the risks linked to the substances they manufacture and market in the EU. They have to demonstrate to ECHA how the substance can be safely used, and they must communicate the risk management measures to the users.

If the risks cannot be managed, authorities can restrict the use of substances in different ways. In the long run, the most hazardous substances should be substituted with less dangerous ones". (ECHA 2020)

Hence, REACH regulation shifts the responsibility and management burden from public authorities to industry and companies with regards to assessing and managing the risks that can be caused by chemicals.

REACH applies to substances manufactured or imported into the EU in quantities of 1 tonne or more per year and generally aims to improve the protection of human health and the environment. EU chemicals industry has been impacted by this regulation on one hand, but on the other it is pushed to create the necessary thriving environment for innovative projects and business models that could be potentially forcing for the deployment of the IS.

Despite the positive aspects that REACH is bringing to the economy and the environment, is constitutes a major barrier to IS as whatever is classified as 'waste' is not considered under the REACH legislation. Only if recycled materials are to be categorized as waste then can come into effect again (Lombardi et al. 2017). In the recently launched new Circular Economy Action Plan (2020) it is stipulated though that a "review of EU rules on restrictions of hazardous substances in electrical and electronic equipment and provide guidance to improve coherence with relevant legislation, including REACH and Eco-design" will be performed (European Commission 2020b).

Programmes and roadmaps that have been set into force in the past twenty years do indeed indicate a strong determined direction towards circular ecosystems and thus send an encouraging enabling signal to further expand IS initiatives across the EU, supporting these with the required funding streams under the EU Grant Schemes (e.g. Horizon Europe, Horizon 2020, LIFE+ Programme, etc.)

The emerging patterns and themes stemming from the policies that indirectly or directly support industrial symbiosis are the following:

- **"Pollution/waste reduction**: managing waste, creating less waste, diverting waste from landfill
- **Resource efficiency**: increased resource productivity and decoupling economic growth from resource use and its environmental impact.
- **Materials security**: addressing critical dependence on certain raw materials
- **Greenhouse gas (GHG) emissions reduction**: lowering carbon emissions
- **Green growth**: creating jobs through activities that also create environmental benefits
- **Eco-innovation**: driving innovation with associated environmental benefits" (International Synergies Ltd. and IFKA 2014)

4 Recommendations for the EU policy framework

Based on the analysis of the information collected in this study, it has been identified that despite the existence of policies around reuse, repair and recycling on the EU agenda, a more comprehensive and holistic policy framework on industrial symbiosis could be pivotal in scaling up its implementation.

According to the report *Cooperation Fostering Industrial Symbiosis*, published by the European Commission (2018), the success of adopting industrial symbiosis solutions depends on the existence of a suitable regulatory framework, supported by shared knowledge and capacity building along multiple stakeholders (e.g. through clarifying and harmonising vocabulary, promoting best practice facilitation and processes, build on existing knowledge of industrial symbiosis opportunities to facilitate replication), pushes incentives towards waste valorisation (e.g. through well-functioning secondary markets and harmonised criteria for 'by-products' and 'End of Waste' status) and creates favourable condition for symbiotic activities (e.g. by enhancing trust to conduct a transaction with

another business counterpart). Moreover, key areas such as planning instruments, finance and strategic investment to support and accelerate the adoption of synergic solutions (Artola et al. 2018).

As it has been stipulated by Dr. Y. Tao that policy is an enabler of IS, and "governmental institutions could contribute to shaping the context underlying industrial symbiosis development by setting clear objectives and supporting business eco-efficiency activities, penalising lower hierarchy waste management options (e.g. landfill and incineration), and providing information and facilitation assistance for companies to identify economically viable alternatives for their waste". (SCALER 2020a)

This section provides an outline of the gaps identified and recommended ways forward.

4.1 Introduce an action plan or a strategic framework for IS

IS supports the environmental sustainability at the crossroads of engineering, ecology and economics. The European Union and its Member States, through their national and regional plans, are key to developing policies and regulations that can support symbiotic relationships across industries and companies within their regions. The EU has so far issued a number of Directives, Actions Plans, Communications, Strategies, Decisions, Best Practices, Referrals and Opinions to support implementation.

In literature it is apparent that there is a significant number of case studies analysis which assess IS initiatives in Europe. At present, this large number of policies tackle directly the subject matter of circular economy under the pan-European scope, leaving a gap on a concrete and direct guidance to encourage, implement, and facilitate symbiotic solutions by various stakeholders along a given supply chain. An updated overview of IS activity in Europe, along with a coherent policy framework that will put Industrial Symbiosis directly at its centre, could thus be beneficial to help scale the uptake of industrial symbiosis.

Since Industrial Symbiosis is currently not yet widely implemented and there seems to be a lack of a policy plan to specifically stimulate industrial symbiosis practices, it is important to enrich the current regulation framework at the pan-European level by introducing a European IS Specific Section in the Circular Economy Action Plan. It has also been suggested that it would be beneficial to generalise IS in order to promote the circular economy (EESC 2019), as IS is an important option for establishing a circular economy. This position is reinforced by other EU publications: "the EU should consider developing an industrial symbiosis strategy as a follow-up of the implementation of the circular economy action plan

and explore the feasibility of legislation to require Member States to promote it in the future" (European Commission 2018b).

In order to exploit the full potential of industrial symbiosis, there is a need for a long-term public support framework for CE and industrial symbiosis, including consistent strategies and mandatory objectives (Johnsen 2015). This can be supported by an extensive analysis on the interlinkages among different industrial sectors, taking into account the effects of legislation and policy aspects with a systemic approach. For example, even though the WFD introduced a relevant framework for waste management across the EU, it has also brought barriers and opportunities to IS either by limiting the availability of materials useful to IS or with waste "resulting from a production process the primary aim of which is not the production of that item", meaning that materials, instead of being qualified as "waste", are characterised as by-products and thus enhance the IS processes.

4.2 Holistic approach towards the production cycle

At the EU level, there is a multitude of documents and policies that aim to regulate the different product design stages and aim to define its characteristics and the treatment of the used products (e.g. energy efficiency, chemical consistencies, repair and re-use, recyclability, longevity, reparability, durability, upgradability, etc.). It appears that most policies concentrate on the production and waste stages of a product's lifecycle, whilst the in-between steps are not reinforced enough.

Authors like Costa et al. (2009) and Paquin and Howard-Grenville (2010), identify that existing regulation structure focusses more on "end of pipe" solutions like treatment and disposal, instead of targeting solutions with the highest possible waste hierarchy and contributing to landfill diversion (Costa et al., 2010; Paquin and Howard-Grenville, 2009). Thus, a direction and stimulus of actors to choose waste management solutions that prioritise reduction over reuse, reuse over recycling, and recycling over (energy) recovery from disposal could be beneficial.

Great potential could lie in considering the production process in a holistic way, aligning different process steps, their potential and linking the process impacts. Additional value could be capitalised by prioritising prevention policies, reutilisation incentives or extended producer responsibility schemes that directly influence the production system, as well as stimulate and harmonise the usage phase at the EU level; policies that would enhance the middle stages of the production process could also increase value.

Such a policy framework would revolutionise the way industries design, make, use or handle waste of their own products, while reducing environmental impacts, alleviating competition for scarce resources and reducing production costs (European Commission 2020b, 2020c).

Clear targets at the EU-level that would aim to "reduce the Union's overall ecological footprint with respect to use of material in absolute terms" would also support circular economy / industrial symbiosis uptake (Ellen MacArthur Foundation 2015; Pantzar and Suljada 2020).

4.3 Update status of secondary materials and by-products

Ambiguity on the status of secondary materials and by-products has been one of the major challenges that prevents businesses and institutional investors to engage in Industrial Symbiosis endeavours and creates market barriers to compete against cheaper primary resources. In some cases, this is a result of conflictive legislation that pose restrictions to the uptake of secondary materials, e.g. by associating them with risks of cross-contamination (Artola et al. 2018). Additionally, there seems to be a lack of regulation advocating homogeneous waste streams, leading to the current mixed waste streams that are costly for business.

Policies can boost this market by harmonising the application and defining specific minimum requirements, and/or allowing flexibility to use secondary materials and by-products instead of primary raw materials. Thus, setting up adequate conditions for secondary material and by-product markets would contribute to advance the circular economy and allow companies to retain value and materials in Europe (Artola et al. 2018). This would create confidence in the markets by introducing standards or frameworks that emphasize on the quality, performance, and detail specifications of the secondary raw materials.

The Eco-design Directive addresses this challenge from the perspective of environmental impact of products, but could widen its approach to increase effectiveness as the eco-design processes differ from industry to industry, from company to company and from product to product (FISSAC 2017).

It is suggested that the EU should strengthen even more its secondary raw materials market and take even more measures by revising existing directives and regulations, so as to reduce the export of secondary raw materials from the EU and enhance the interaction of industries

by promoting and allowing more secondary streams available for European companies (Tello and Weerdmeester 2016).

4.4 Streamlining existing fiscal policies

Financial incentives encourage the initiation of industrial symbiosis and circular economy projects and networks.

There could be instances whereby the effects of the one Directive may partly contradict the intention of another (e.g. Landfill Taxes vs. Eco-Design vs. REACH vs. WFD vs. WEEE). This may result to restricted practices (e.g. on waste re-use), and thus create difficulties for industries to apply the concept of IS (Neves et al. 2019b; Neves et al. 2019a; Neves et al. 2020).

Taking a holistic approach around existing fiscal policies related to IS could prove beneficial, by continuously reviewing feasibility of subsidies, taxes, grant schemes, carbon prices, etc. and either enhance or constrain them and make substantial efforts to facilitate investments in IS networks.

Another level would be the review and elimination of environmentally harmful subsidies and possible harmonisation of taxes across Member States. In support of this, many studies and reports indicated that the "EU policy needs to abolish environmentally harmful subsidies and establish the taxation of pollution and natural resource use." (Johnsen 2015).

Literature also suggests to move towards a tax reform that will aim to convince Member States to gradually shift "tax burden from labour to the use of non-renewable energy and virgin raw materials" (Pantzar and Suljada 2020). Thus, make primary raw materials more expensive as compared to reused or secondary raw materials and stimulate the dialogue towards more synergetic industrial production systems. The EU could initiate a programme that will aim to create a tool identifying potential investors that could make use of certain by-products available in a given area (Kallay and Szuppinger 2017).

Private investment will also be part of the mix towards industrial symbiosis implementation: it is therefore important that policies provide the stability required to enhance this.

4.5 Policies supporting increased coordination across IS facilitating entities and networks

The dynamics of industrial cooperation and systems continues to be an area that requires further research and progress (Kusch 2015) as industrial systems are complex adaptive systems.

Existing and already established networks in a given place can motivate industrial actors to create new synergy linkages and extend the network to new companies (Neves et al. 2019b). In many instances, certain industries act locally as pivotal players of IS, leading negotiation and implementation of synergies. However, in most cases companies could benefit from additional resources and capacity building to further develop synergies within their ecosystem.

Policy could support the creation of mechanisms to bring together practitioners, policymakers, regional authorities and other stakeholders and thus aim to create suitable types of industrial symbiosis initiatives and facilitate implementation and coordination of projects. Important steps in this respect have been taken with initiatives like CircLean: European Network of Businesses and SMEs for Industrial Symbiosis[1]. It could also potentially indirectly support the connection of a multitude of actors in existing initiatives (e.g. CircLean, SCALER, SYMBI, TRIS, etc.) or existing innovation communities (e.g. EIT KICs), hubs for circularity (proposed by SPIRE PPP), industrial park owners and operators, local leaders at the municipalities where symbiosis is taking place etc.

4.6 Policies supporting skills, and capabilities development necessary for IS

There is a significant gap around the knowledge and information across the industrial players, companies and SMEs around the potential that Industrial Symbiosis can have on the society, environment and economy.

[1] https://www.interregeurope.eu/policylearning/news/6858/kickstarting-circlean-european-network-of-businesses-and-smes-for-industrial-symbiosis/?no_cache=1&cHash=a87bf77dd7d31a821fbcd29d1dcf44a7

Lack of knowledge around IS related topics may lead to a reluctance of companies to implement industrial symbiosis actions and symbiotic relationships. The study of Technopolis "Cooperation Fostering Industrial Symbiosis" has identified significant capacity gaps both for companies and IS facilitators, for example lack of technical capability to evaluate environmental risks and benefits associated to synergies, the capacity to adapt and implement complex regulation (e.g. 'End of Waste' criteria) and ability to negotiate with industrial actors (Artola et al. 2018).

SCALER has also identified the need to develop institutional capacity for IS, including building of policy, technological and network facilitation knowledge, as well as relationship management skills and networking knowledge amongst national/federal, state/regional and local governments (Vladimirova et al. 2018).

EU policy can play an active a role in supporting capacity development in relation to IS, not only for industries but also potentially for policymakers and IS facilitators in order to be able to turn knowledge and experience into action. Support could be provided towards assisting knowledge/vocational training institutions for creating new curricula integrating the principles of IS.

4.7 Enhancing trust

There is an emerging pattern that non-technological issues are major obstacles to industrial symbiosis in Europe e.g. contracting issues, sharing of information among different companies, relevant standards, regulations linked to utilisation of waste, or characterisation of chemicals, minerals, etc.

Policies could support trust-building among different actors and data streams, by supporting the streamlining of information through relevant standards, or by e.g. supporting interoperability or information disclosure which is now closed mostly due the competitive landscape companies operate in.

The EU via its regulatory frameworks, available funding and policies can support the establishment of trusted, safe, and secure relationships and platforms for those stakeholders interested in implementing industrial symbiosis.

Conclusions

Industrial activities have rapidly increased worldwide, intensifying the consumption rates of earth's finite natural resources. The radical increase on the demand of materials and energy link to the current practices of production and consumption, which are both based on an unsustainable linear business model, focussing primarily to extract raw materials in order to manufacture new goods and products, which will then be consumed and finally be disposed. Such a "traditional" pattern will be gradually leading to a shortage of our planet's resources, which are already scarce. However, the depletion of materials, because of industrial activities can be significatively overcome by implementing *Industrial Symbiosis*.

Industrial symbiosis synergies are "transactions where organizations acquire underutilized resources (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials that are not the primary output of the production process) from the organization(s) that generates them, and integrates these as inputs of their production process" (CEN, 2018). This approach has been highlighted in the New Industrial Strategy for Europe, which is part of the EU Green Deal, and aim to address the needs of the industry sector to become greener, more circular and more digital while remaining competitive on the global stage.

The success in achieving ambitious goals requires the holistic and ambitious policies. Great potential could lie in policies that aim to tackle multiple levers around the current industrial system that could lead to a raid and transformative change (e.g., skills, behaviour, market structures, information flows, organisational governance, and finance).

Policy recommendations proposed are:

- Introduction of an action plan / strategic framework for industrial symbiosis
- A holistic approach in policies related to the production cycle
- Updated status of secondary materials and by-products
- Streamlining of existing fiscal policies
- Policies supporting increased coordination
- Policies supporting skills and capabilities development in relation to industrial symbiosis
- Policies/regulatory frameworks that can enhance trust between actors

ANNEX: EU Policies linked to Industrial Symbiosis

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Circular Economy Action Plan	Policy	Resource efficiency	Macro	(European Commission 2020b)
Industrial Strategy	Policy	Pollution and waste reduction	Macro	(European Commission 2020a)
"Use-value" is back: new prospects and challenges for European products and services (own-initiative opinion)	Finance	Green Growth	Macro	(EESC 2019b)
Directive 1999/31/EC on the landfill of waste	Production Systems	Waste	Macro	(EU 2018)
Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU	Policy	Resource Use and Consumption	Macro	(EU 2017)

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Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
European Environment Agency: Circular Economy in Europe	Citizen engagement & Behaviour Change	Green Growth	Macro	(European Environment Agency 2016)
European Resource Efficiency Platform: Manifesto & Policy Recommendations	Policy	Resource efficiency	Macro	(EREP 2013)
DG Enterprise: Green Action Plan for SMEs	Business Model	Resource efficiency	Macro	(European Commission 2013)
DG GROWTH: Sustainable Industry: Going for Growth and Resource Efficiency	Policy	Resource efficiency	Macro	(European Commission 2012a)
Green Employment Initiative: Tapping into the job creation potential of the green economy	Skills	Green Growth	Macro	(European Commission 2014a)
Commission Decision of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council (2014/955/EU).	Production Systems	Waste	Macro	

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Shipments of waste Regulation (EU) No 660/2014	Production Systems	Waste	Macro	(EU 2014)
DG Environment: Priority for industrial policy in recommendation	Policy	Green Growth	Macro	
Waste Target Review	Production Systems	Waste	Macro	(Hogg et al. 2013)
General Union Environment Action Programme to 2020 "Living well, within the limits of our planet"	Technology	Green Growth	Macro	(European Council 2013)
DG Environment: Eco-Innovation Observatory Annual Report	Policy	Eco-innovation	Macro	
European Resource Efficiency Platform Recommendations	Policy	Resource efficiency	Macro	(EREP 2013)
Green Paper on 2030 framework for climate and energy policies	Finance	Green Growth	Macro	(European Commission 2013)

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Directive 2013/56/EU of the European Parliament and of the Council of 20 November 2013 amending Directive 2006/66/EC of the European Parliament and of the Council on batteries and accumulators and waste batteries and accumulators as regards the placing on the market of portable batteries and accumulators containing cadmium intended for use in cordless power tools, and of button cells with low mercury content, and repealing Commission Decision 2009/603/EC	Technology	Waste	Macro	
DG Regions: Connecting Smart and Sustainable Growth through Smart Specialisation –exemplar	Technology	Eco-innovation	Micro	(European Commission 2012b)
Guide to Research and Innovation Strategies for Smart Specialisation (RIS3)	Business Model	Waste	Meso	
A Stronger European Industry for Growth and Economic Recovery - Industrial Policy Communication Update	Technology	Technology	Macro	
Towards a job-rich recovery	Skills	Green Growth	Macro	(European Commission 2014a)

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Standardisation Regulation (EU) No 1025/2012	Policy	Production	Macro	(EU 2012b)
Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance	Production Systems	Production and Waste Management	Macro	(EU 2012a)
DG Enterprise and Industry: Sustainable Industry: Going for Growth & Resource Efficiency – exemplar	Production Systems	Resource efficiency	Macro	
Tackling the challenges in commodity markets and on raw materials - Strategy	Production Systems	Material Security	Macro	(EESC 2011)
A Roadmap for moving to a competitive low carbon economy in 2050	Policy	Emission reduction	Macro	(European Commission 2011c)
Eco-Innovation Action Plan COM 899	Policy	Eco-innovation	Macro	(European Commission 2011a)
Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC Text with EEA relevance	Production Systems	Production	Macro	(EU 2011b)

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment	Production Systems	Waste	Macro	(EU 2011a)
Directive on industrial emissions (Large combustion plants directive)	Production Systems	Emission reduction	Macro	
'Being Wise with Waste' – Best Practice	Production Systems	Waste	Macro	(EU 2010)
Commission Decision of 30 April 2009 completing the technical requirements for waste characterisation laid down by Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from extractive industries (notified under document number C (2009) 3013),	Production Systems	Waste	Macro	(EU 2009)
Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products	Technology	Resource Use and Consumption	Macro	(EU 2009)

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Sustainable consumption and production and sustainable industrial Policy Action Plan	Production Systems	Production	Macro	(European Commission 2008b)
The raw materials initiative — meeting our critical needs for growth and jobs in Europe	Skills	Green Growth	Macro	
Green Public Procurement COM (2008) 400	Finance	Green Growth	Macro	(European Commission 2008a)
EU Waste Framework Directive (WFD)	Policy	Waste	Macro	(European Commission 2019b)
EU Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC	Production Systems	Waste	Macro	(EU 2006)

Policy Instruments in support of IS	System lever	Policy Themes	Lines of Action	Reference
Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC	Production Systems	Production and Waste Management	Macro	(EU 2006)
EU Directive on Packaging and Packaging Waste Directive 94/62/EC	Policy	Waste	Macro	
Thematic Strategy of Prevention and Recycling of Waste (COM 666)	Production Systems	Waste	Macro	(European Commission 2005)
End of Life Vehicle Directive	Technology	Waste	Macro	(European Commission 2000)
Resource Efficiency Flagship Initiative	Policy	Resource efficiency	Macro	

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